

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

June 1953

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Chesterfield Station of Virginia Electric and Power Company

**Topographical Influences
on Dispersal of Stack Gases** ▶

Preparing Steam Generating Unit for Service ▶

**Engineering and Technical
Problems of Atomic Power** ▶

POTOMAC RIVER STATION

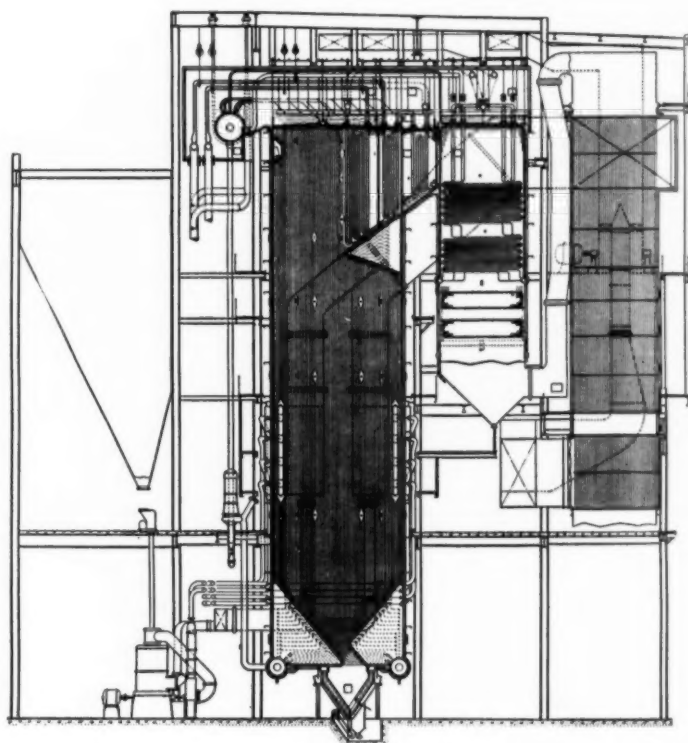
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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 24

No. 12

June 1953

Feature Articles

- Topographical Influences on Dispersal of Stack Gases..... by Gordon H. Strom and James Halitsky 40
- Preparing Steam Generating Unit for Service at O. H. Hutchings Station by R. L. Novak 45
- Engineering and Technical Problems of Atomic Power..... by Walter H. Zinn 49
- Formation of Sulfur Trioxide in Flue Gas..... by Prof. Torsten Widell 53
- Steam Plant Cuts Unit Costs over Diesel Operation at Menasha.... by P. E. Widsteen 57
- High-Pressure Hot Water at Air Bases..... 59

Editorials

- For Your "Must" Reading List.... 39
- External Tube Corrosion..... 39
- Wanted: A Centripetal Professional Force..... 39

Departments

- Review of New Books..... 63
- Catalogs and Bulletins..... 66
- Advertisers in This Issue..... 72
- Volume Index..... 75

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GERALD S. CARRICK
Business Manager

ALFRED D. BLAKE
Editor
GLENN R. FRYLING
Assistant Editor

CARL G. UDELL
Circulation Manager

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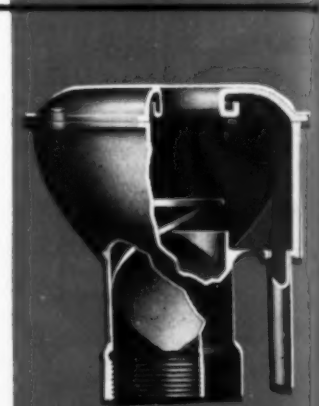
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For Your "Must" Reading List

Declassified versions of reports by four industrial teams which appraised the prospects of joint production of electric energy and fissionable material from reactors have just been published by the Atomic Energy Commission. Representing between one-third and one-fourth of the bulk of the classified information in the original studies, these eagerly awaited reports merit serious examination by all interested in power generation.

For their persistent efforts in seeking and finding ways of making this information available to the entire engineering profession, two members of the AEC Advisory Committee on Industrial Information are deserving of credit and appreciation. They are Andrew W. Kramer, editor of *Power Engineering*, and Stanley A. Tucker, publications manager of ASME, who prepared the declassified condensed versions of the reports.

Although comparatively few specific reactor design details are included, the reports have considerable value because they point to some of the pressing problems that the electric power industry will have to face before nuclear energy becomes commercially feasible. Readers who are interested in these reports by Commonwealth Edison—Public Service, Dow Chemical—Detroit Edison, Monsanto Chemical—Union Electric and Pacific Gas & Electric—Bechtel are urged to send 25 cents to the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., for the 88-page "Reports to the U. S. Atomic Energy Commission on Nuclear Power Reactor Technology."

External Tube Corrosion

The source of one of the biggest losses in practically all fields is corrosion. Various estimates have been made as to the magnitude of such loss, but its extent defies all attempts at evaluation. It is not alone the material damage that counts, but also the labor involved in replacements and often the outage factor which may outweigh the material cost.

Although extensive research has gone far to alleviate the extent of such damage in certain fields, the problem remains a major one.

In the power plant field both internal and external corrosion must be guarded against. Proper and close attention to the feedwater has done much to control the former, but the latter is likely to occur with some fuels whenever flue gas at relatively low temperatures comes in contact with economizer or air preheater surface. In fact, this is a very pressing problem both here and abroad, judging by current discussions before engineering groups.

Many studies are being made, both laboratory and field, as to the efficacy of various protective coatings. Here, aside from the properties of the coating, much

depends upon the preparation of the basic metal before its application. Also, the cost of applying the coating must be weighed against its probable protective life.

Of course, sulfur in the fuel is the villain. It is present in residual fuel oils and to various degrees in most coals. It burns to SO_2 which, in turn, is oxidized to SO_3 . Just how this takes place has been the subject of various opinions which are discussed by Professor Widell elsewhere in this issue.

Wanted: A Centripetal Professional Force

As these words are being written the American Medical Association is holding its 102nd Annual Meeting in New York City. More than sixteen thousand physicians are in attendance to hear some four hundred technical papers scheduled for presentation.

Why mention this in a publication whose readership is predominantly made up of engineers? If one considers the current state of organization, overorganization and disorganization of the engineering profession the answer will be apparent.

Last September the American Society of Civil Engineers celebrated its Centennial with a mammoth inter-society meeting in Chicago. Looking back to a realistic appraisal of that meeting reveals an almost incredible fragmentation of the engineering profession. Indeed, it would be difficult to find a better example of the growth of professional provincialism and narrow specialization.

How can one explain the contrastingly different roles that the AMA and the ASCE have come to assume in their respective professions? Actually, both societies had their origins at about the same time in the mid-nineteenth century and benefited by reasonably comparable advances in their basic underlying scientific disciplines. Yet despite the rapid growth of medical specialties and the divergent forces that such interests must have imposed upon the structure of the AMA, that society has continued to exert leadership for the entire medical profession. On the other hand the ASCE which originally represented *civil*, as contrasted with *military* engineering, continued to represent one specialized field while innumerable other specialized societies sprang up over the years. This is not meant as a criticism of the ASCE but rather the trend in engineering field.

Today the engineering profession might be compared to a rotating machine that is badly out of balance. The centrifugal forces of narrow specialization and the inertia of vested society interests have gotten out of hand. Engineers know what to do to bring the machine into balance. Somehow they must find and muster the strong and effective leadership that can create the centripetal forces out of which an effective unity organization can grow.

Topographical Influences on Dispersal of Stack Gases

By GORDON H. STROM* and JAMES HALITSKY†

THE path followed by stack gases leaving a smokestack is determined by two sets of conditions. One defines the dynamic and thermal properties of the gas, the other defines the dynamic and thermal properties of the air stream which flows past the top of the stack.

In normal operations gases leave the smokestack with an upward velocity and with a temperature well above that of the surrounding air. Both these properties cause the gas to rise; an increase in either one accelerates the upward motion. The gas exit velocity and temperature are determined principally by the design and operating conditions of the plant.

Air motions, however, are generated by uncontrollable meteorological factors and are strongly influenced by the topography of the earth's surface. The general air motion, or wind, is substantially parallel to the ground, but may be diverted laterally or vertically by obstructions, returning to its original path some distance downwind of the disturbance. The amount of deflection will vary with the size and shape of the object, which may be small, as a one-story dwelling or grove of trees, or large, as a powerplant or cliff. The wind has a leveling effect on the gas stream, which leaves the stack at a flatter angle as the wind speed increases. When obstructions are present the air motions may cause the gas to move downward toward the ground.

The path followed by the gas, called the plume, depends on the relative magnitudes of these two effects. A high gas ejection speed at high temperature, coupled with a low wind speed, will produce a plume which rises rapidly and then levels off gradually at high altitude. This condition is not likely to contaminate the ground.

A serious condition may arise in a strong wind where the dynamics of the air predominate in shaping the plume. Immediately after leaving the stack, the vertically rising gas stream is struck transversely by the horizontally moving air. Layers of gas are torn from the sides of the jet, and the shrinking core is forced to deflect downwind as it rises. The air which would have flowed smoothly over the top of the stack now divides around the jet and comes together behind it in an extremely turbulent manner. At low exit velocities where initial plume rise is small, turbulence caused by air motions around the top portion of the stack is an added factor. This turbulence grows rapidly until it envelops the gas stream, resulting in an infusion of a large amount of air into the gas. The smoke becomes more like a tracer in the general air motion. The gas concentration, however, is still high enough to create a pollution problem if the air motion is such as to carry the gas to the ground.

Types of Air Motions

The general movement of air over a given region is determined by large-scale meteorological factors. Local air motions important to gas dispersal are caused by the thermal structure of the lower atmosphere and by topography, including surface roughness and obstructions.

The flow over flat land is characterized by a uniform velocity above a certain height, and a drop off of velocity below the height, at first gradual, then at an increasing rate until it falls to zero at the ground. The region of variable velocity is termed the shear or boundary layer. Its height varies with surface roughness and the thermal condition of the atmosphere, but for wooded and suburban areas it may be assumed to be roughly 1000 ft in a neutral atmosphere.

This boundary layer owes its existence to the property of "wetting" which is common to all real fluids. The

* Professor of Aeronautical Engineering, College of Engineering, New York University.
† Research Associate, Research Division, College of Engineering, New York University.

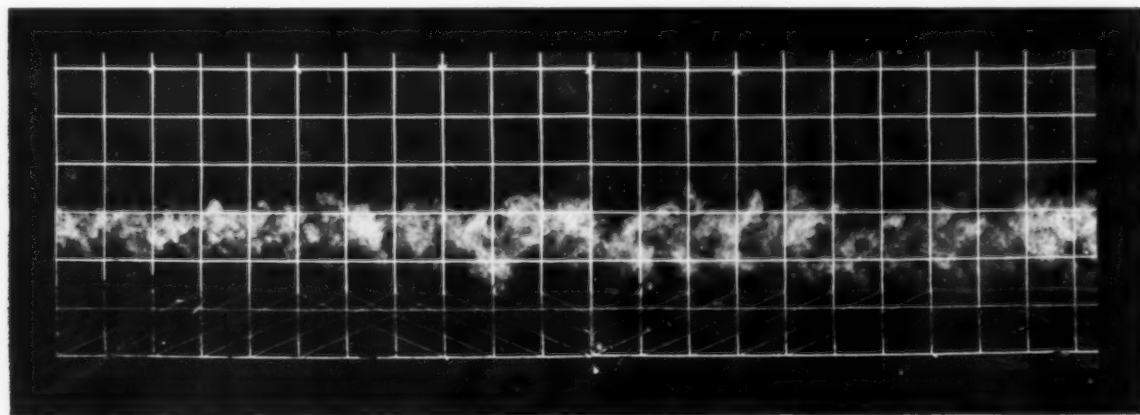


Fig. 1—Smoke plume over level ground

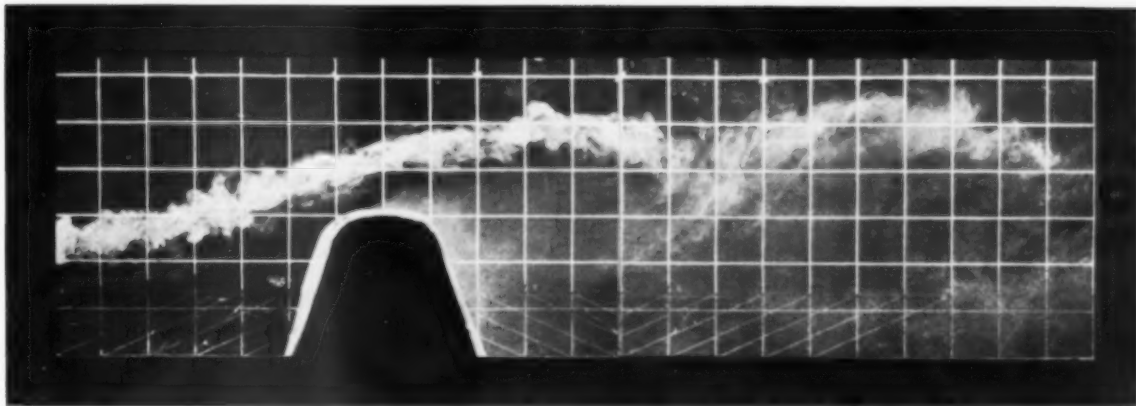


Fig. 2—Smoke plume over obstacle

lowest layer of the horizontally moving air, in contact with the earth's surface, must have zero velocity because it adheres to the surface. The adjacent layer is slowed down by "friction" and in turn slows down the layer above, but to a smaller degree. This process is continued upward until an elevation is reached where the retarding influence of the earth is no longer effective. The mechanism of "friction" is believed to be the vertical interchange of air eddies between layers moving at different speeds. Since these eddies are generated at the ground, the greatest interchange is near the ground and thus the greatest velocity gradients are produced here. At higher altitudes these small eddies of high intensity have grown in size but diminished greatly in intensity so that the velocity gradients and turbulence are small. At an elevation of one-third of the boundary layer height the velocity is roughly 85 per cent of the maximum velocity. When caused by surface conditions as described above, the eddies are the source of fluctuating air motions called mechanical turbulence.

Superimposed on the mechanical turbulence are thermal currents generated by heating or cooling of the earth's surface due to radiation from the sun or to outer space. When warmed, the earth warms the lower layer of air in contact with it, makes it lighter and causes it to rise. Other layers descend to take its place and are in turn warmed and rise. Thus an additional circulation is generated which augments the mechanical turbulence. Conversely, a cool surface will cool the adjacent air which will tend to remain below the warmer layers and thus damp out the mechanical turbulence. A condition may sometimes exist in which no thermal currents are generated. In this case the atmosphere is called a neutral atmosphere, and the turbulence in the air is entirely mechanical. The balance of this discussion will be limited to the case of the neutral atmosphere.

The dispersal of stack gases therefore becomes intimately associated with the degree of mechanical turbulence in the air. Turbulence not only causes the gas stream to lose its initial homogeneity, but it governs the rate of diffusion of the gas, in some cases bringing it to the base of the plant in the form of a cloud. The type and magnitude of mechanical turbulence are controlled solely by topography.

Whether a topographical feature will cause a disturbance of sufficient magnitude to influence a gas plume from a conventional plant is a matter of scale. Over

flat farm land or wooded areas, a succession of hedges, crops or groves of trees may blend together to form a general surface roughness which may cause sharp velocity fluctuations at crop level but which will be damped out at elevations of several hundred feet. At the other end of the scale, large mountains will cause deviations in the general horizontal flow, but the relatively small plant would feel only a change in prevailing wind direction without a change in turbulence. The principal topographical features affecting the smoke trail are natural formations or fabricated structures of size comparable to the height of the power plant itself.

In the course of experimentation in the smoke study wind tunnel at New York University, four general types of topography were found to have characteristic flows; these are

1. Flat or gently sloping land with or without surface roughness, and without large local structures.
2. Large local obstruction (comparable to size of plant).
3. Sudden rise of ground.
4. Sudden drop of ground.

The flow over these types of topography will be described and illustrated with photographs of tests made in the New York University wind tunnel.

As described previously, the flow over flat terrain is essentially horizontal, and the turbulence at stack height is small. It may be expected, therefore, that a smoke plume emitted from a stack at an elevation of about 300 ft will remain aloft for a considerable distance and

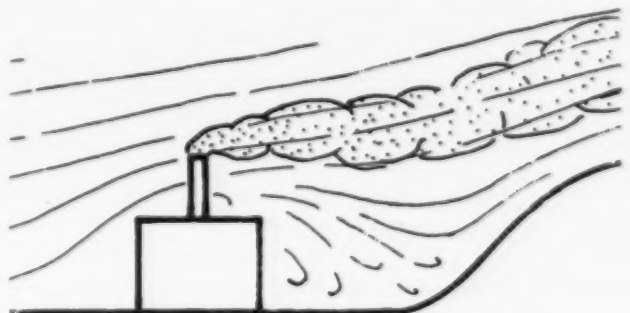


Fig. 3—Smoke plume in an "uphill" wind—sketch of stream lines

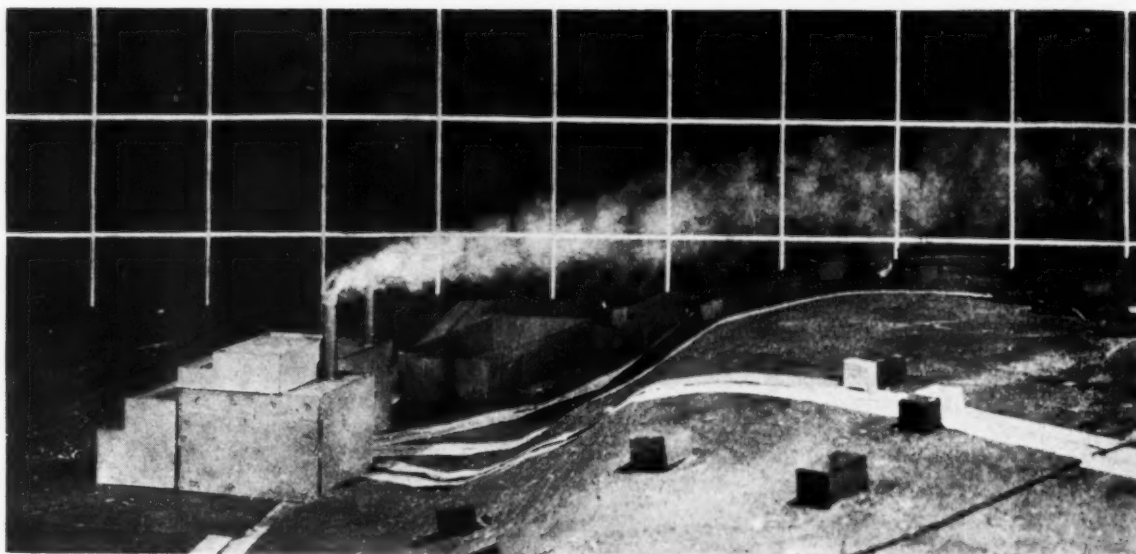


Fig. 4—Smoke plume in an "uphill" wind as indicated in New York University wind-tunnel study on model of the Hudson Plant of the Rockland Light and Power Co. Courtesy of Burns & Roe, consulting engineers

retain its compact shape, provided that no large obstruction introduces disturbing large-scale eddies. Fig. 1 shows a smoke plume from a single horizontal stack. There is no disturbance below the point of emission so that the smoke moves horizontally downwind with little diffusion.

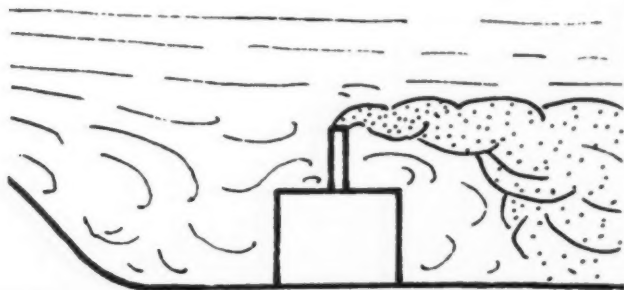


Fig. 5—Smoke plume in "downhill" wind—sketch of stream lines

When the ground slopes gently upward or downward for a considerable distance, it may be assumed that the general air flow will be parallel to the ground, and the boundary layer and turbulence characteristics will be the same as in the case of flat ground.

The second case is that of an obstruction whose height is roughly that of the plume. This may represent flow over a ridge of ground, a large building, or over the plant itself, if the building height is comparable to stack height. Fig. 2 shows such a condition. The smoke is seen to rise with the airstream as it sweeps over the hill but to fall behind the hill as large eddies bring heavy concentrations to the ground. These concentrations then diffuse to create a general haze downwind of the hill. The haze appears to attain its maximum concentration near the rear upper surface of the hill. The line dividing the air smoothly flowing over the front upper surface from the turbulent air over the rear upper surface is clearly traced out by the haze boundary.

When a plant is located at the foot of a sharply rising hill which terminates in a plateau at about the elevation

of the top of the stack, the smoke trails in the "uphill" and "downhill" winds are found to be strikingly different. Air motions are similar to those on the upwind and downwind sides of the obstruction. The air is deflected upward as it meets the face of the hill and increases in velocity to a maximum near the crest. It levels off over the plateau and becomes substantially uniform. Streamlines of motions and path of a smoke plume are shown in Fig. 3. No noticeable turbulence is caused by the presence of the hill. The wind tunnel test photograph of Fig. 4 shows the smoke plume to have quite regular dispersal characteristics. Although the stack has approximately the same elevation as the hill, the plume rises and remains clear of the ground within the range of the photograph. If the hill were more abrupt than shown in Fig. 4, some turbulence might occur at the crest.

When the wind direction is reversed, the flow pattern undergoes a major change. As the air moves over the crest of the hill or down from the plateau, the main body of the airstream separates from the surface and leaves

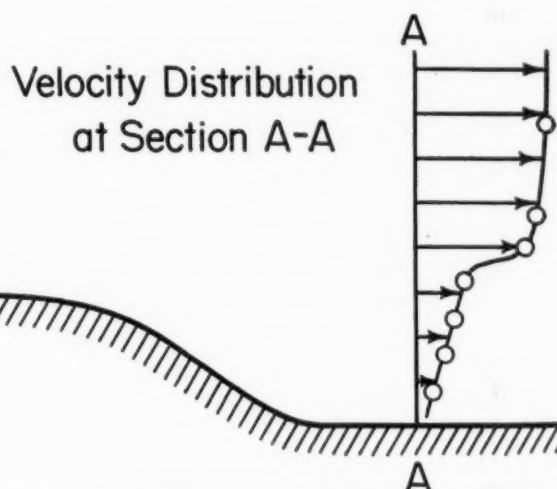


Fig. 6—Velocity distribution in a "downhill" wind—pitot static tube survey

the lower region in a turbulent state as shown in Fig. 5. The velocity survey in Fig. 6 shows that the main stream does not follow the contour of the hill. The velocity measurements were taken with a Pitot-static tube insensitive to turbulent fluctuations. Low velocities shown for levels below the crest of the hill indicate the stagnant nature of the turbulent region. Fig. 7 shows how stack gases discharged into the turbulent region are dispersed throughout and reach ground level in a short distance. This condition is similar to that shown in Fig. 2, but the turbulent region downwind of the obstacle is larger because the air is deflected upward and rises above the crest before descending.

Comparing "uphill" and "downhill" winds it is evident that the latter cause a more serious pollution problem because of the large amount of turbulence generated. Any remedial measures such as modification of building shape to reduce turbulence will have little effect because the turbulence caused by the hill is so large as to far outweigh any beneficial effects of the building modifications. Any measures short of raising the plume above the turbulent region by stack height or high exit velocities will yield little improvement. "Uphill" winds present less of a problem. Remedial measures, effective for flat topography, may be expected to show improvements in this case.

Conclusions

In a neutral atmosphere, two sources of energy influence the path of the stack gases. The power plant provides energy in the form of a hot moving gas stream directed away from the ground. The topography produces a disordered wind energy contained in mechanical turbulence which tends to bring the gases to the ground. The relative strength of the two determines whether ground contamination will occur.

It is apparent that the most favorable topography for minimum contamination is level ground in a suburban or lightly wooded area. However, the power plant designer is constrained to select a river or lakeside location for cooling water. Other industries favor similar sites for transportation facilities. When the river or lake shore

is at the foot of sharply rising ground, as is frequently the case, pollution problems are to be expected.

Level terrain is not sufficient to guarantee freedom from pollution. The largest obstacle to smooth air flow is frequently the power plant itself. The trend in stack design seems to be in the direction of making stacks less obvious by reduction in height or enclosure within other structures. This brings the point of gas emission close to or within the turbulent region created by the building with extremely high pollution as the result.

The countermeasures to these topographical disturbances may be found in plant architecture, plant layout, tall stacks and addition of energy to the stack gas. Wind tunnel tests at New York University have shown that the shape and the orientation of the building to the wind alter the turbulence characteristics markedly. From the viewpoint of minimum obstruction to the wind a low open type of construction is indicated. Addition of energy to the gas may be done in the form of increased temperature or velocity. In either case this energy is irretrievably lost and the overall efficiency of the plant is reduced.

When plants are expanded and sizable structures appended to existing buildings, pollution may be created where none existed before, due to the increased obstruction to the wind. The gases which originally had sufficient energy to escape from the building turbulence are caught in the stronger downwash and brought to the ground. In such cases a large capital outlay is required for fans and associated equipment in addition to increased operating cost in supplying more energy to the stack gases.

Most wind tunnel investigations of the past have been made on existing plants where a pollution problem was found to exist after a plant was constructed. Aside from loss of public good will such situations can lead to costly reconstruction of plant structure and equipment. At the present stage of development it is difficult to estimate whether a new plant or modifications to an existing plant will have undesirable pollution characteristics. Scale model wind tunnel experiments offer one of the best available means to a solution.

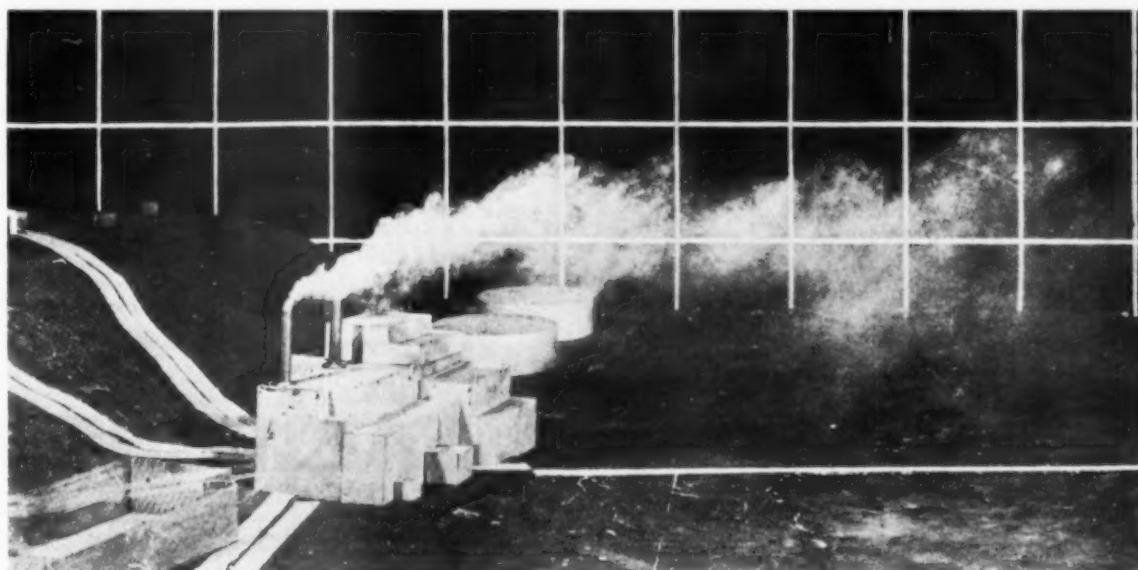
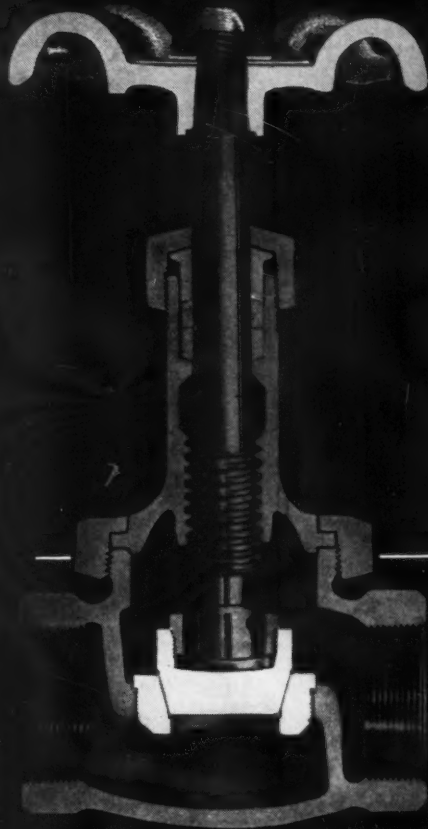


Fig. 7—Smoke plume in a "downhill" wind—photograph of scale model of Hudson plant of the Rockland Light and Power Co. in New York University smoke study wind tunnel. Courtesy of Burns & Roe, consulting engineers



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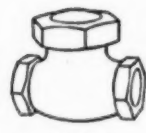
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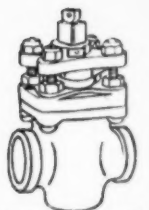
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Preparing Steam Generating Unit for Service at O. H. Hutchings Station

By R. E. NOVAK

The Dayton Power and Light Company

The O. H. Hutchings Station¹ of the Dayton Power & Light Company, which was designed for an ultimate capacity of 360,000 kw, at present contains five 60,000-kw G-E turbine-generators, the first two of which are supplied with steam at 1350 psig, 950 F by 500,000 lb per hr C-E boilers. Units 3, 4 and 5 are also of 60,000-kw rating but operate on the reheat cycle with steam of 1500 psig, 1000 F initial and 1000 F reheat temperatures. Each is served by a C-E boiler of 430,000 lb per hr steam flow. Steps taken toward preparation of No. 5 unit for service are here given in detail.

THE primary objective of an alkaline boil-out of a new boiler is to remove the water- and alkali-soluble and saponifiable materials from the internal surfaces of the boiler. Such materials consist chiefly of the lubricants used during the boiler erection and the temporary rust preventative coatings applied to certain surfaces after shop fabrication to prevent atmospheric rusting.

In order to attain the above-mentioned aims, the No. 5 boiler of O. H. Hutchings Station was prepared for an alkaline boil-out on October 21, 1952. The boiler was filled by way of the lower waterwall blowdown headers with well water until approximately firing-level height was attained. To keep a check on the water level, a temporary round gage glass was installed on the main steam drum. To this water through a vent pipe in the main steam drum, 360 pounds of caustic soda, 850 pounds of trisodium phosphate, 120 pounds of sodium nitrate, and 30 pounds of Santomerse "D" were added. This gave a chemical ratio of 3, 3 and 1 of the first three ingredients for every 1000 pounds of water in the boiler. At 4:00 p.m. the addition of chemicals was complete. With the vent closed at 4:30 p.m. all lower torches were ignited and gas firing was initiated at a slow rate to dry the boiler slowly. By 6:30 p.m. the water had expanded in the boiler so that the water level was out of sight in the temporary gage glass. The boiler was then drained by each lower waterwall header drain until the water level was approximately 1 in. above the bottom of the

gage. At 11:00 p.m. the gas leaving the economizer was 250 F. At 12:00 a.m. a test gage installed on the main steam drum indicated 10 psig. On October 22 at 9:30 a.m., or seventeen hours after firing was begun, the desired 300 psig was obtained. At this stage of heating the maximum temperature of the gas entering the economizer was 495 F, while the maximum temperature of the gas leaving the economizer was 465 F. At 11:30 a.m. the lower waterwall header and the economizer were blown down so that the water level in the gage glass dropped 2 in. The water blown away was replaced with condensate brought through the economizer.

Analyses of the samples taken from various blow-downs are listed in Table 1. It will be noted that there were no chemicals added to the water after each blow-down to compensate for those lost through blowdown, and yet, the concentration left after the final blowdown was more than sufficient to do the work intended. Sampling around the boiler, as the analyses show, indicated that the chemicals were thoroughly and uniformly distributed throughout the boiler.

Silica checks indicated soluble silica constant; 12 ppm of this silica concentration is due to the well water. The remainder is due to the chemicals and possibly some boiler silica. The interesting thing to notice is the oil pickup. Maximum oil concentration occurred approximately four hours after 300 psig was obtained. It is believed by many, and the oil checks tend to verify this, that after about four hours of boiling the solution has dissolved all of the oil and grease there is to dissolve, and the rest of the time spent is what might be termed "insurance boiling."

On October 23 at 11:30 a.m. the pressure on the boiler was dropped to 30 psig at which time the boiler was drained. By draining with this pressure still on the boiler, it was hoped to get a better flushing action. The boiler was then allowed to cool without any forced air circulation. On October 24 at 10:00 a.m. the boiler was inspected. The drums were very clean with no evidence of oil slick or foreign matter. The unit was washed down and then prepared for acid cleaning.

Acid Cleaning

Acid cleaning, as is stated in Section VII of ASME Boiler Construction Code under "Cleaning Out New Boilers," is an operation conducted with inhibited acid solution primarily for the purpose of removing mill scale and products of corrosion. On October 27 at 9:20 a.m., with the drum temperature at 175 F and lower header temperatures around 140 F, the boiler

¹ A description of the initial installation of one 60,000-kw turbine-generator and two 500,000 lb per hr, 1350 psig, 950 F boilers appeared in COMBUSTION in January 1949.

was drained. At 11:20 a.m. the acid was started into the boiler by way of the lower waterwall blowdown headers. Table 2 shows the time for the various steps necessary in the acid cleaning of this boiler. The method used here is called the "dilute fill" method.

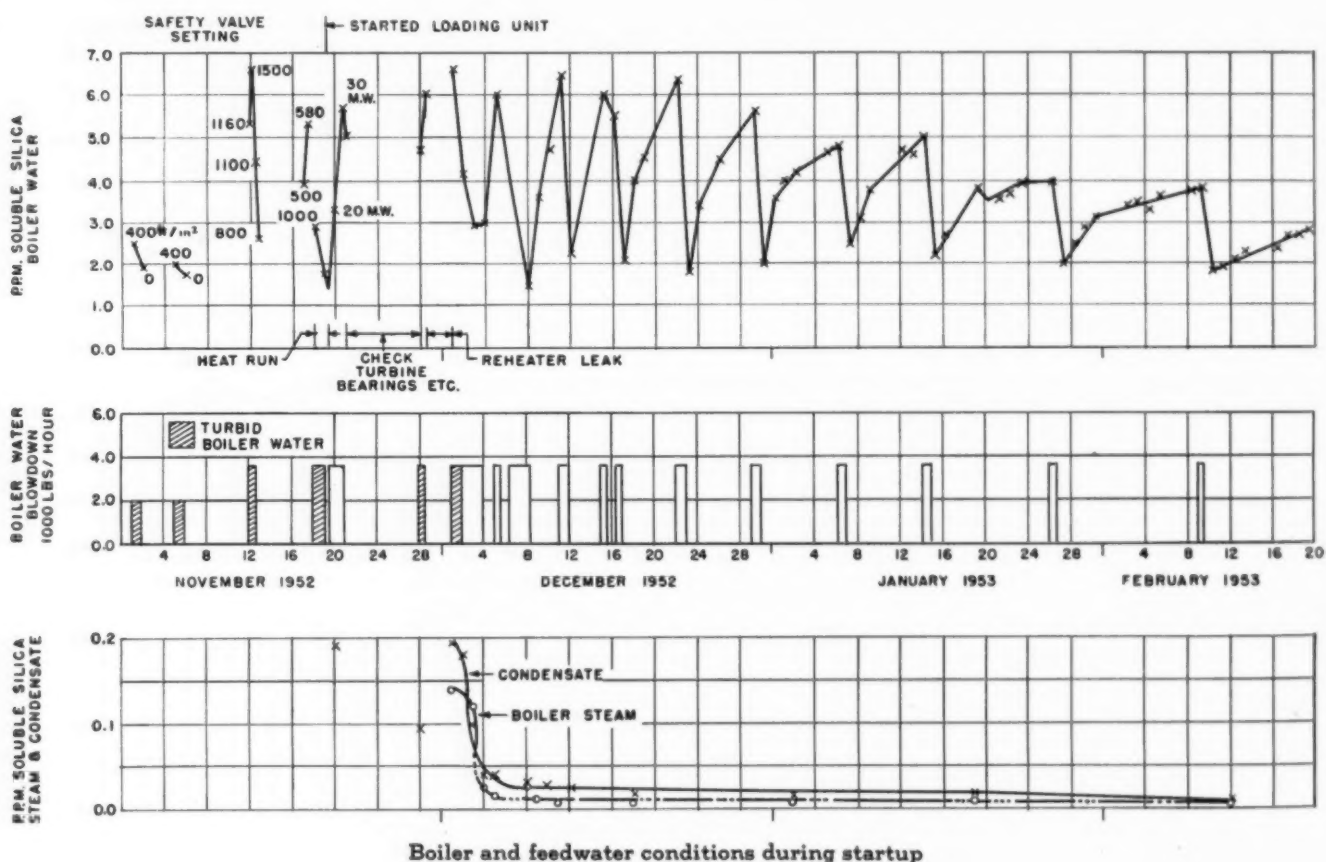
A 1-in. line carrying steam at 400 psig and 700 F was used to heat the acid solution to 152-156 F. At 3:30 p.m. the boiler and economizer were full of approximately 3 per cent inhibited hydrochloric acid solution. At 7:57 p.m. after about 4 hr of soaking the boiler was drained. Nitrogen gas was used in conjunction with this draining to help prevent formation of iron oxides. At 4:30 a.m. after the final rinse a 1 per cent solution of sodium carbonate was pumped into the boiler. The boiler was then fired to get 100 psig and was neutralized at this pressure for one hour.

In the above process of acid cleaning, 2000 gal of 28 per cent inhibited hydrochloric acid were used. This

superheaters were then blown to atmosphere (bypassing the stop valve) until the boiler pressure dropped from 400 to 200 psig. On the first blow solids could be heard rattling in the pipe as they went on their way to the outside of the building. The first blow of steam was black as it left the pipe. Subsequent blows were clear.

On November 5 the piping was rearranged to give the reheater a similar blow. The blowing pressure went from 400 to 200 psig; six blows were made, each one lasting approximately eight minutes.

On November 24, the No. 5 turbine was available for inspection. In the low-pressure end of the turbine housing there was no evidence of black iron oxide. This proved the value of superheater and reheater blows. The condenser housing and tubing of this No. 5 Unit as well as the turbine exhaust hood were clean. However, on the last stage of the turbine there was noticed a brown, tacky deposit, easily scraped with the thumb-



Boiler and feedwater conditions during startup

gave an initial concentration of 3 per cent. The final concentration at the time of draining was 2 per cent. The amount of mill scale that 1 per cent of the above acid is theoretically capable of dissolving amounts to 973 pounds. Analysis of the drain acid showed that it contained 864 pounds of iron oxide and 7 pounds of insolubles.

Blowout Program

In order to minimize iron oxide fouling of control valves and iron oxide deposition on turbine blading, a blowout program was instituted on November 1. The primary and secondary superheaters were given six blows. The boiler was pressured up to 400 psig and the

nail. This deposit was less than a thousandth of an inch thick. It looked like a rust preventative (used on auxiliary equipment) that had vaporized and then condensed on the last stage of the turbine.

The hotwell and condensate system up to the condensate pumps was inspected at this time. On the screens protecting the condensate pumps were found sticks of wood, paper, broken glass (light bulbs), mill scale and rust. All of this was held together by a tacky substance (no doubt the same substance as seen on the last stage of the turbine). The material that had accumulated on the screens, weighed nine pounds.

It took 16 hr of wide open blowdown (3600 lb per hr through blowdown valve on separating drum) to clear

the boiler water of iron oxide. When the associated feedwater piping was put into service, the total amount of blowdown needed to clear the boiler water amounted to 71 hr. It took 117 hr of wide open blowdown to get the boiler water silica low enough to put the blowdown on an intermittent schedule. The accompanying figure presents boiler and feedwater conditions during the startup.

The fact that the boiler was blown down only 16 hr to clear the water helps to show the merit of acid cleaning. This was achieved at a cost of about \$16 due to heat degradation and water lost. Companies which have not acid cleaned their boilers have reported weeks of "black water" conditions and, therefore, by the same token weeks of blowdown. Three weeks of blowdown would cost \$500.

Avoiding "Black Water" Conditions

Financial savings in blowdown is but a minor reason for acid cleaning. One of the very important reasons for acid cleaning new boilers is to avoid several objectionable conditions attendant upon "black water." These factors include (a) dirty water with possible accumulations to the point of impeding circulation of heat transfer, (b) possible obstruction of steam separators and drums, with attendant unbalance in steam flow in drums, (c) aggravation of carryover with iron oxide depositing in superheaters, strainers, turbine valve and control mechanism, and turbine blading.

The frequency of applying blowdowns to the boiler to lower silica concentrations is steadily decreasing. Silica values, determined as late as February 12, 1953, on the boiler steam and condensate are in the neighborhood of 0.007 ppm silica in the condensate and 0.005 ppm silica in the boiler steam.

TABLE 1—ANALYSES OF BLOWDOWN SAMPLES

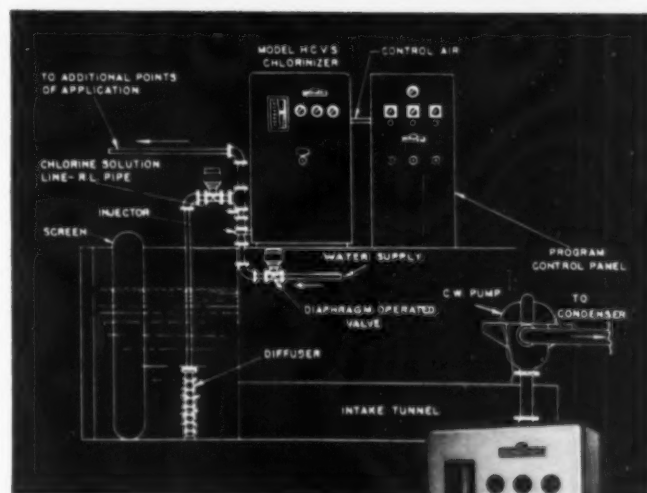
11:30 A.M.	1:30 P.M.	3:30 P.M.	5:30 P.M.	9:30 A.M.
3430* NaOH	3010 NaOH	2640 NaOH	3192 NaOH	2686 NaOH
2910 Na ₂ PO ₄	2640 Na ₂ PO ₄	2520 Na ₂ PO ₄	2310 Na ₂ PO ₄	2200 Na ₂ PO ₄
40 SiO ₂	44 SiO ₂	41 SiO ₂	41 SiO ₂	40 SiO ₂
10 Oil	21 Oil	16 Oil	7 Oil	8 Oil

* Parts per million.

TABLE 2—DETAILED RECORD OF ACID TREATMENT OF NO. 5 BOILER

Time	Temp.	Conc.	Details
8:00 a.m.	...	...	On location, hooking up.
10:00 a.m.	...	...	Start draining boiler. Temperature of upper drum 164 F, lower drum 108 F.
11:20 a.m.	152	3	Start pumping.
3:20 p.m.	152	3	Boiler full and overflowing vent. It required 4 hr to fill the boiler. After 3 hr, the boiler was full to the top of the gage glass and economizer was full. Pumping rate was slowed up so as not to run too much solvent over the vent.
5:55 p.m.	...	...	The two sample lines on the top headers were opened and water added to boiler very slowly.
6:00 p.m.	...	...	Lines on top headers overflowing.
	125	2	East upper header.
	125	2.2	West upper header.
	135	...	Temperature of main steam drum.
	125	2	Lower north header.
6:00 p.m.	125	2	Lower south header.
7:55 p.m.	...	...	Start draining boiler using nitrogen flush. Only four drains on lower headers open. Economizer also drained.
8:15 p.m.	...	2.2	Drain sample.
8:45 p.m.	...	2.2	Drain sample.
8:55 p.m.	...	...	Boiler drained.
9:00 p.m.	...	...	Start first flushing using pump truck.
11:15 p.m.	...	...	Boiler full, overflowing vent on drum.
11:18 p.m.	...	...	Overflowing sample lines on top headers.
11:25 p.m.	...	...	Start draining boiler using nitrogen; drains on boiler, economizer and primary superheater open.
12:10 a.m.	...	...	Boiler drained.
12:25 a.m.	...	...	Start second flush.
2:40 a.m.	...	...	Boiler overflowing vent on drum.
2:43 a.m.	...	...	Overflowing vent on upper headers.
2:50 a.m.	...	...	Shut down. Primary superheaters full.
2:55 a.m.	...	...	Start flushing, using nitrogen.
3:40 a.m.	...	...	Boiler drained.
3:48 a.m.	Start pumping M-3 solution (1500 lb).
4:15 a.m.	Shut down.
4:30 a.m.	Left location.

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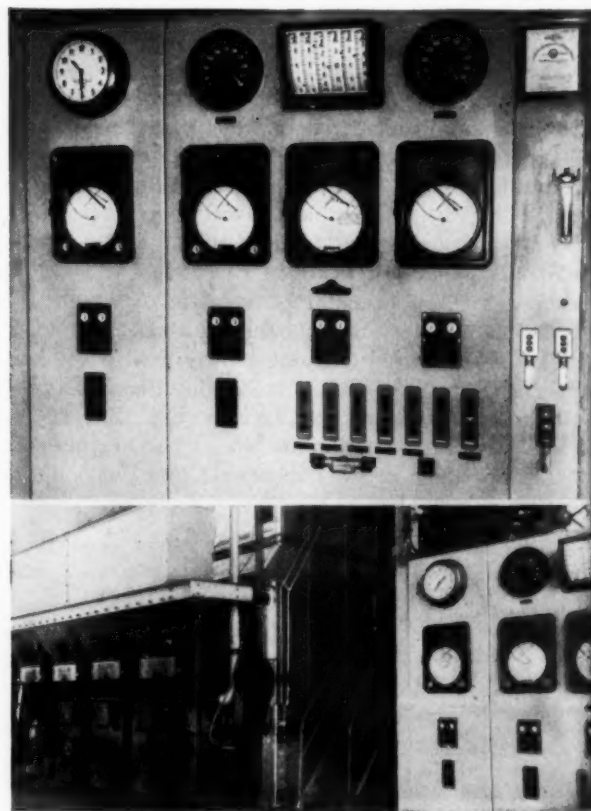
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Engineering and Technical Problems of Atomic Power*

By WALTER H. ZINN

Director, Argonne National Laboratory
Atomic Energy Commission

A discussion of fuel supply and probable costs, reactor types, moderator and structural materials, coolants, corrosion problems, shielding, and what has been accomplished to date in the actual production of power.

FREQUENTLY I have been asked how soon this country will have an operating central-station nuclear-fueled power plant. My answer has been "Four or five years after it has been definitely decided to construct and operate such a plant." Bearing in mind that it would probably take three years just to construct a power plant with a nuclear reactor as the heat source, it is clear that I have allowed a year or so for design and engineering and no time at all for resolving doubts about the technical feasibility or for debating the merits of various ways of going about the job. If the question were "How soon will we have an *economically competitive* nuclear-fueled plant?" I would avoid a direct answer by saying: "We will know what it takes to make an economically competitive nuclear power plant only after we have gained experience in operating the first reactor which is designed and constructed specifically as a central-station power plant."

Cost of Nuclear Fuel

We are encouraged to believe that the cost of fuel for a nuclear plant can be less than the cost of coal for present plants, although a basic difficulty is that no one knows how much an operating company would have to pay for the uranium. Miners are paid \$3.50 per pound for producing uranium while in the ore, and it may be assumed that this figure is multiplied ten times in the process of putting it in a form suitable for use in a reactor, thus making the basic cost \$35 per pound. From this it might be concluded that if all of a piece of uranium were to be converted to fission products, the fuel cost of generating electricity would be a little more than one hundredth of a mill per kwhr. However, most of the natural uranium is U^{238} of which 99.3 per cent is of the nonfissionable variety.

The term nonfissionable as here used has a special meaning. It means that this isotope of uranium (U^{238}) does not fission when it absorbs neutrons whose speed is in equilibrium with the medium in which they diffuse, hence, "thermal" neutrons. It does fission when bombarded by "fast" neutrons. To separate the U^{235} con-

tained in the natural uranium involves a very costly process which would make the fuel cost for generating electricity much too high. Pure, isotopically separated U^{235} will be used in some of the military mobile reactors, but is not likely to be the fuel of atomic central-station power plants.

Regenerative Reactors

If the two isotopes of uranium are used together, advantage can be taken of the fact that in a reactor more than heat can be generated. By allowing some of the neutrons released in the fission to be captured by the nonfissionable U^{238} , plutonium which is fissionable is created. This is being made every day in the research and production reactors of the U. S. Atomic Energy Commission and in reactors in Canada, England, Norway, Sweden, France and presumably Russia. This regeneration of fissionable material, which takes place automatically and cannot be prevented if uranium in the form as provided by nature is placed in the reactor, makes all the difference. It is not just the 0.7 of 1 per cent of U^{235} which can be consumed but also some of the plutonium that is generated. Hence it is not necessary to separate physically the U^{235} and the U^{238} . The extent to which this regeneration process can be put to work depends on a number of factors that influence the design of the reactor. If for each quantity of fissionable material consumed, 80 per cent as much plutonium is formed—that is, plutonium is formed with a conversion ratio of 8 to 10, a value easily reached in practice—the fuel available to the reactor is not just the amount of U^{235} provided by nature but five times as much. This means that not only can a substantial fraction of the contained U^{235} be burned, but actually a larger amount of U^{238} . A conservative appraisal indicates that 1 per cent of the total is burned and gives a fuel cost which is not the earlier, unrealistic figure of 0.01 mil per kwhr but more nearly 1.0 mil, a value comfortably below the fuel cost in a coal-burning plant.

To achieve greater percentage usage of the uranium requires higher values of the conversion ratio, until finally when the conversion ratio approaches 1.0 and beyond, a high percentage usage can be attained. Whether or not it can approach 100 per cent will depend on the magnitude of the inevitable losses not of neutrons in the reactor, for the conversion ratio includes these, but of material in the various chemical and metallurgical operations required. A high conversion ratio is necessary not only from the cost viewpoint but, more importantly, for the proper usage of uranium.

* Condensation of a paper presented at the American Power Conference at Chicago, March 25, 1953.

Is There Enough Uranium?

It is pertinent to inquire as to how much uranium is required to keep a plant running and whether such amounts can reasonably be demanded from our mining industry. It is easier to think of this matter in connection with a generating station of conventional size, hence a nuclear-fueled plant of 150,000 kw capacity and a thermal efficiency of 25 per cent may be considered. For an 80 per cent load factor and the type of regenerative operation just described, namely 1 per cent burnup, 20 tons of natural uranium would be required annually as fuel. This is a modest amount and illustrates the advantage of nuclear fuel in the matter of transportation. How many such plants could be supported by our domestic production of ore is not known, but certainly it would be enough to get an infant nuclear-fueled power industry going. Technical developments will bring higher usage, permitting more and more nuclear plants.

"How often would such a reactor need to have its fuel charge replenished?" is another question of some interest. It is a familiar fact that for a nuclear reactor to operate at all, it must contain at least the "critical amount" of nuclear fuel. For instance, the first graphite-uranium reactor, the University of Chicago experiment at Stagg Field, contained 41 tons of natural uranium. More than the critical amount of nuclear fuel can be charged into the reactor, but then some nonfissionable absorber of neutrons must also be added in order to maintain the reaction under control. Ordinarily, the coolant is such an absorber and thus it can be seen that a practical graphite-natural uranium reactor would have a fuel charge in excess of the amount in the first reactor. Suppose we add the year's requirement of 20 tons for the 150,000-kw electric plant to the 41 tons so that the reactor is charged with 61 tons of normal uranium. Also, it is to be recharged when 1 per cent has been consumed by fission. The reactor then would require a new fuel charge every three years.

Generating impurities in the fuel while it is being violently bombarded by the fission product fragments and fast neutrons can cause physical distortion and even collapse. Deterioration of fuel under such bombardment is called "radiation damage."

Moderator Materials

So far only problems directly connected with the uranium fuel have been considered, but there are others connected with the enormous amount of heat energy that must be carried from the fuel to the steam generating equipment. Consideration must be given to the choice of moderating materials, structural materials and, most important, the cooling medium.

Table 1 gives an estimate of the relative effectiveness of four moderating materials, namely, ordinary water, heavy water, beryllium, and graphite. In the second column, the relative appetite of these for wastefully absorbing thermal neutrons is given. This, however, is only one of the criteria for selecting a moderator. A second is the number of collisions required to slow a neutron down from its velocity as emitted in fission to the thermal energy. Since it is desirable to have both absorption and the number of collisions small, a useful measure of effectiveness of the moderator is the product, which is given in the last column. On this basis, heavy

water is superior and light water least desirable. However, availability and cost must also be considered. In the early stages of this development, graphite was chosen over heavy water because of its availability. Beryllium is costly and suffers the added disadvantage of being a subtle health hazard. Despite its poor standing, light water is always worth considering as a moderator because

TABLE 1—MODERATING MATERIALS

Material	Relative Neutron Absorption per $\text{Cm}^3 \times 10^3$	Number of Collisions Required to Thermalize	Absorption \times No. of Collisions
Light water	22	18	396
Heavy water	0.06	25	1.5
Beryllium	1	86	86
Graphite	0.4	114	45

of cheapness and availability. It should also be clear that in a power reactor, high temperatures are involved, for which reason graphite and beryllium are especially suited. If water is to be used as moderator, it must be either insulated from the high temperature of the fuel or pressurized.

Structural Materials

In Table 2 some structural materials which have been or could be used in reactors are listed. In the second column, relative neutron absorption per unit of volume is indicated. In the third column, is listed the relative neutron absorption for pipes of equal strength and identical internal diameters. The superiority of zirconium is apparent. Magnesium and aluminum, although much better than stainless steel, are ruled out because of corrosion difficulties and low melting point. Steel and zirconium are the likely prospects for the construction of pipes and supports for the internal parts of an elevated-temperature reactor. Steel imposes a severe penalty on the reactor operation because of its large parasitic capture of neutrons. It is not surprising that the AEC and its contractors have expended a large amount of effort in obtaining and learning how to use purified zirconium.

TABLE 2—STRUCTURAL MATERIALS

Material	Relative Neutron Absorption per $\text{Cm}^3 \times 10^3$	Relative Neutron Absorption for Pipes of Equal Strength (20 C)	Melting Point (Deg F)
Magnesium	3.5	10	1200
Aluminum	13	102	1230
Stainless steel	226	234	~2730
Zirconium	12.6	16	3330

Unfortunately, zirconium occurs with hafnium from which it can be separated only with difficulty. Moreover, the natural zirconium-hafnium mixture is no improvement on steel with regard to neutron absorption. Corrosion resistance, although not indicated in the table, is very important with regard to structural materials. This cannot be considered without specifying the coolant.

Reactor Coolants

Table 3 is a comparison of various coolants that are being used or have been suggested for power reactors. The second column lists relative neutron absorption. Helium rates best on this account, with heavy water, bismuth-lead, sodium, and light water following in that order. Since the reactor is to produce power, the coolant

must permit operation at some elevated temperature and must permit a sizable temperature rise as it passes through the reactor. Some assumed temperature increases are shown in the third column. A large temperature rise is desirable for efficient use of the nuclear fuel. The average heat flux which these coolants permit is given in the fourth column. What is "average" is a

TABLE 3—COOLANT COMPARISON

Coolant	Relative Neutron Absorption per $\text{Cm}^2 \times 10^3$	Assumed Temperature Rise (Deg F)	Average Heat Flux (Btu/Sq Ft Hr)	Power Pump (Lb/Min/- MW)	Reactor Size (Sq Ft/- MW)
Helium at 2000 psi	~ 0	1000	5×10^4	41	68
Light water	22	180	50×10^4	316	6.8
Heavy water	0.06	180	50×10^4	316	6.8
Sodium	11	360	200×10^4	500	1.6
Bismuth lead	3	180	50×10^4	5600	6.8
Oil	...	...	...	...	...

matter of choice; heat rates of one million Btu per sq ft per hr are high but necessary for the power reactor. In the fifth column, the mass flow of coolant per unit of power output is given. This is only one of the factors which determine pumping power, but it indicates the relative standing of the coolants. Pumping power is a direct drain on the salable power; consequently, high pumping charges should be avoided. Heavy liquid metals carry a considerable handicap in this regard. If volume be considered rather than mass flow, helium also rates unfavorably with respect to pumping power. In the last column, the square feet of cooling surface required per unit of power is shown. Generally speaking, this will determine the reactor size, and it can be assumed that reactor size, the cost of building the machine, and the inventory charge on the fuel are more or less proportional. Pressurized helium appears to call for a relatively much larger reactor than either water or liquid metal. Therefore, it is understandable that the Hanford Works reactors are water-cooled, that the Argonne National Laboratory-Westinghouse designed submarine reactor is water-cooled, and that the General Electric designed submarine is sodium cooled.

Irradiation causes dissociation of compounds which is one of the reasons liquid metals are used as reactor coolants. In the case of water, the dissociation products are gases and can be managed. Without specific data on a particular oil, a comparison cannot be made.

Corrosion

With high heat fluxes, cooling surfaces must not foul. Also, corrosion products in the circulating fluid become radioactive and add to the maintenance and shielding difficulty. High-temperature, high-pressure water is a fairly corrosive medium, but with proper treatment is usable. Fortunately, zirconium is quite resistant to attack under these conditions. Hot sodium presents few corrosion problems for the metals in the middle of the periodic table, especially if precautions are taken to keep it free of contaminants, notably oxygen.

The corrosion resistance of the uranium fuel itself in the coolant atmosphere is a vital point. All coolants with the exception of helium, when passing through a reactor, become radioactive. This radioactivity is usually associated with just one nuclear species and decays with a specific half-life. For instance, in the case of water the induced radioactivity has a half-life of eight

seconds and therefore a very short time after leaving the reactor this radioactivity vanishes. Sodium becomes radioactive with a half-life of fifteen hours and, although it takes several weeks for this radioactivity to die to a negligible amount, it does disappear. If, due to corrosion, any of the uranium fuel gets into the cooling stream, it carries with it fission products and some of these have half-lives as much as several years. This means that a cooling system contaminated with fission products will remain permanently radioactive unless cleaning measures can be effectively instituted. This is difficult. For these reasons, in a water reactor a protecting sheath on the uranium is used.

Compatibility, corrosion-wise, of the uranium fuel with its coolant has a great deal to do with the extent to which the protecting sheath must be made perfect. If the hot fuel corrodes very rapidly so that measures to shut off the machine and reduce the temperature are not effective before a sizable amount has entered the cooling stream, troublesome contamination can result. If the reactor must be shut down frequently for such maintenance, its value as a source of power is much depreciated.

This aspect of corrosion is in addition to the usual one of interference by the corrosion products with the heat transfer properties of surfaces. It makes corrosion research basic to the development of nuclear reactors.

In comparing the two most likely coolants, namely, sodium and pressurized water, we can strike a balance sheet something like this. Although the pressures required for water-cooled power reactors are not phenomenally large, making the system tight against leakage of radioactive water vapor is a problem. It calls for the development of such devices as canned rotor pumps, as has been done for the Argonne-Westinghouse submarine reactor. By and large, however, the engineering of the pressurized water system can call very heavily upon established methods. Sodium with a boiling point of 1616 F requires no pressurizing. It can be brought out of the reactor at as high a temperature as corrosion and the general management of a very radioactive substance permit. The integrity of the piping system must be beyond question and may require the development of such devices as double-walled piping systems and electromagnetic pumps. Electromagnetic pumps are completely sealed and require for their operation only that a current of electricity pass through the pipe carrying the liquid metal. Higher temperatures are possible with sodium than with water, thus leading to more efficient conversion to electrical energy.

Shielding

Shielding for the reactor of a central station power plant is not a question of major significance. Ordinary concrete of sufficient thickness will do. The magnitude of the radioactivity in the circulating cooling system is not to be underestimated. Both the water-cooled and sodium-cooled reactors, for instance, require heavy shielding around the cooling pipes exterior to the reactor. In the case of sodium cooling approximately five feet, and in the case of water cooling, three feet of concrete are required.

The picture of the power reactor which the foregoing discussion has no doubt created is a structure containing moderating material and rods or pipes carrying uranium

cooled by water or sodium. Curiously enough, the only reactors which so far have produced any amounts of electrical power do not fit into this description. The first reactor to produce electricity, the Argonne National Laboratory's Experimental Breeder Reactor, operates on fast neutrons and thus does not require a moderator. The homogeneous reactor experiment, which Oak Ridge National Laboratory recently announced has generated some electricity and is moderated, but contains no solid uranium pieces.

The Experimental Breeder Reactor

The experimental breeder reactor uses as materials of construction only metals and is cooled by a liquid metal, an alloy of sodium with potassium. The temperature of the issuing coolant is 660 F which is adequate to generate 400 psi steam with a considerable amount of superheat. As the name for this reactor suggests, its main purpose is to explore the possibility of achieving a high conversion ratio of uranium to plutonium or plutonium to plutonium. Maintaining the chain reaction with fast neutrons gives an excellent chance for the so-called nonfissionable U^{238} as well as U^{235} to be fissioned and to contribute neutrons to the chain reaction. This "fast effect," which is a bonus for the conversion ratio, is also present in the moderated neutron reactors but to a lesser extent depending on the thickness of the uranium pieces used. This experimental reactor has been operating for more than a year without serious difficulty and regularly produces electrical power sufficient to supply the laboratory in which it is housed. Thermal neutron reactors have been operated reliably for many years and it is gratifying to find that the fast neutron breeder reactor is having the same experience.

The Homogeneous Reactor

The homogeneous type of reactor, which essentially is a vessel containing a solution of fissionable fuel in a moderating liquid, is important because it eliminates many of the problems associated with radiation damage of the solid fuel. It also has the obvious advantage that the fuel of the reactor can be gotten in and out through piping rather than requiring the mechanical handling which is a characteristic of the solid fuel reactors. An additional advantage is the possibility of having the fuel solution flow directly to a chemical processing operation in order to remove fission products. With these advantages come certain disadvantages. The solution containing the fuel must be pumped through heat-exchangers outside of the reactor vessel. Since now all of the fuel passes through the heat-exchangers, they become highly contaminated with radioactive fission products. Therefore, one of the most serious problems with the homogeneous reactor is the construction of a cooling system of extremely high integrity, since maintenance will be very difficult and probably must be done by remote control.

Reactor Location

Several dozen reactors have been operating in the world for some little time. All contain sizable amounts of radioactivity; for the large production type reactors operating at high power, it is a prodigious amount. No operating failure of these reactors has caused any hazard to the environs. On the basis of such experience, confidence is growing that reactor operation can be made as

safe as other industrial operations. It is only fair, however, to point out that recently in releasing to farming the Wahluke Slope in the State of Washington, the Atomic Energy Commission announced that for safety reasons no towns or cities should be established within 25 miles of the Hanford reactor area. It qualified this statement with the further observation that the Hanford reactors are unique in design and that for other reactors, the hazard is not so great. One can expect that an expanding military use of reactors and the beginning of a nuclear power industry will lead to the development of reactors and techniques that will limit and minimize the hazard.

To sum up this résumé of reactor types, it is fair to say that no one type has all the desirable features and no disadvantages. Only experience will bring about the evolution of the most successful reactor system.

Granting that there are sound grounds for believing that, technically and economically, atomic power is possible, there remains a question which has been asked by some scientists and some officers of our government. The question is, "What reasons are there which call for this country to devote any of its money or technical talent to the development of central station atomic power?" My answer can be summed up in these three statements:

First, the United States has led the rest of the world in the development of atomic energy as a military weapon. It has unparalleled resources of technically trained manpower and specialized equipment. In the light of this, does it make sense, and do the American people want to willfully refuse to make the additional effort required to realize from atomic energy its major peaceful use? I think the answer is no.

Second, the atomic bomb and other nuclear devices play a leading, if not overwhelming, rôle in the defense planning of this country. Even an infant nuclear power industry would broaden the base of technically trained manpower on which our atomic superiority in considerable measure depends, and it would increase and disperse facilities which could be converted to support our atomic arms.

Third, and most important, the fossil fuel resources of this continent and the world are not inexhaustible. Neither are fissionable materials inexhaustible, but they can provide substantial amounts of power, in terms of the world use of power, for a considerable time and thus help bridge the period between the petering out of fossil fuels and the successful use of solar energy or some other permanent source of energy.

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Formation of Sulfur Trioxide in Flue Gas*

By PROF. TORSTEN WIDELL,
Stockholm, Sweden

A review of the conclusions of different investigators as to the manner in which sulfur trioxide is formed from oxidation of SO_2 . Calculations as to the rate of CO_2 formation and curves showing the influence of certain factors are included.

SULFUR trioxide is an unfavorable component of flue gas and causes certain operational difficulties. Although the sulfur in the fuel is largely converted into SO_2 , sulfur trioxide is formed from the further oxidation of SO_2 to SO_3 . Different investigators generally agree up to this point, but are not in full agreement as to the exact mechanism of formation. According to Harlow (1) the oxidation happens at a relatively low temperature on the surfaces of the superheater. Whittingham (2), however, believes that sulfur trioxide is formed in the flame at a relatively high temperature by oxidation of SO_2 with atomic oxygen. Counter opinions contend that Whittingham's theory is not possible since at high temperatures the equilibrium goes toward SO_2 . On the other hand, the speed of reaction is accelerated strongly by increased temperature, and it is not impossible that a considerable part of the SO_3 is formed at high temperature.

Calculations have been made to ascertain the rate of formation of SO_3 , making allowances for increasing of speed of reaction with temperature. Oxidation of SO_2 can be written



The equilibrium constant of this equation according to Bodenstein and Pohl is

$$\log K = \frac{4927}{T} - 4.567 \quad (2)$$

where

$$K = \frac{P_{\text{SO}_3}}{P_{\text{SO}_2} \cdot P_{\text{O}_2}} \quad (3)$$

and P_{SO_3} , P_{SO_2} and P_{O_2} are the respective partial pressures for SO_3 , SO_2 and O_2 . The SO_3 in equilibrium depends thus upon the amounts of sulfur dioxide and oxygen present. For firing with fuel oil, these values can be assumed constant. The following calculations have been carried out, assuming the sulfur content of the fuel oil to be 2.2 per cent and that there is 25 per cent excess air. In this case the $(\text{SO}_2 + \text{SO}_3)$ of the dry flue gas is 0.122 per cent, or 122 milli per cent. The

water content is about 10 per cent which yields oxygen content of 3.9 per cent. Taking these data as a base, we get the following equilibrium values for SO_3 :

	Temperature, deg C				
	600	800	1000	1200	1400
Equilibrium constant	11.89	1.057	0.201	0.060	0.024
$\text{SO}_3/(\text{SO}_2 + \text{SO}_3)$	0.701	0.173	0.038	0.012	0.005
SO_3 in the dry flue gas, milli per cent	85.6	21.1	4.66	1.42	0.57
Dewpoint of the flue gas, deg C	210	185	150	105	75
SO_2 in the dry flue gas, milli per cent	36.4	100.9	117.3	120.6	121.4

According to experimental investigations of Taylor (4) the correlation between SO_3 content and acid dew-point is nearly independent of the partial pressure of water vapor. The values of dewpoint in the above table are taken from Taylor's measurements. At low temperature the equilibrium mixture contains mainly SO_3 oxidized from SO_2 . However, experimental evidence shows that the dewpoint is seldom higher than 150 C (302 F) which corresponds to the equilibrium composition at 1000 C and in the case of the example, 5 milli per cent SO_3 in the dry flue gas (1 milli per cent =

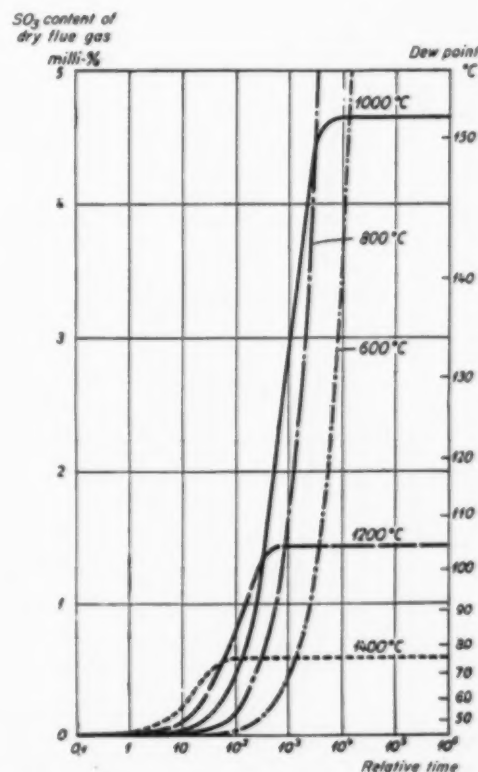


Fig. 1—Formation of SO_3 in oil-fired boiler

* Translated from the *Teknisk Tidskrift*, Dec. 23, 1953, by Stephen Juhasz of Massachusetts Institute of Technology Fuels Research Laboratory.

10⁻³ per cent). The SO₂ content is practically constant and so is oxygen content. Therefore, only the SO₃ content, the temperature and the resistance of reaction control the reaction.

The speed of reaction can be written, according to Fischbeck (5), as

$$\frac{dc}{dt} = \frac{a - c}{w} \quad (4)$$

where

c is the SO₃ concentration

a the same in equilibrium

t is the time

w is the resistance of the reaction

The reaction resistance can be composed of a physical resistance, e.g., diffusion resistance in heterogeneous reactions, and of chemical resistance of reactions. In the actual case shown only the chemical resistance was considered.

In order to be able to make a numerical calculation of the reaction sequence, it is not necessary to know both the temperature and the reaction resistance. The temperatures in different parts of the boiler are known or can be measured. The reaction resistance, however, apparently has not been measured.

It seems to be impossible to judge the absolute value of the reaction resistance. For a qualitative consideration, however, it is sufficient to know how the reaction resistance is changing with the temperature. Such measurements appear not to have been carried out for the reaction in question, but it seems appropriate to make use of knowledge gained from other reactions.

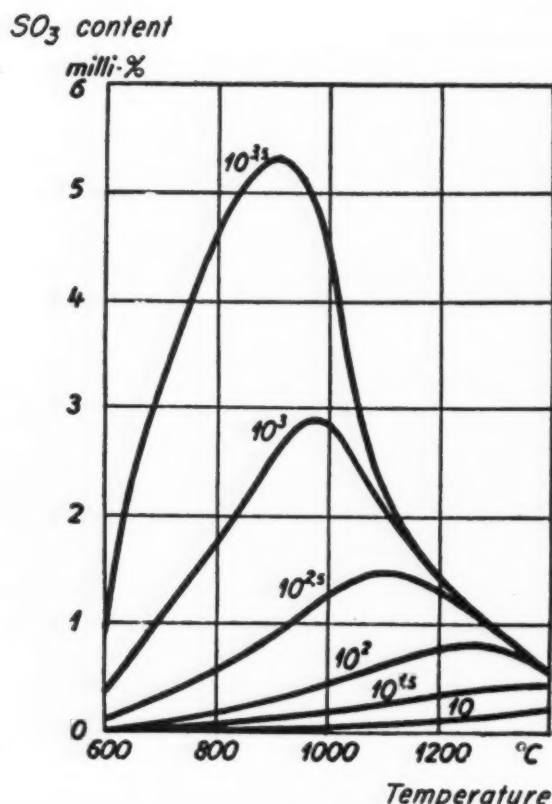


Fig. 2—The influence of time on the formation of SO₃ at constant temperature; the figures on the curve indicate the relative time taken from Fig. 1

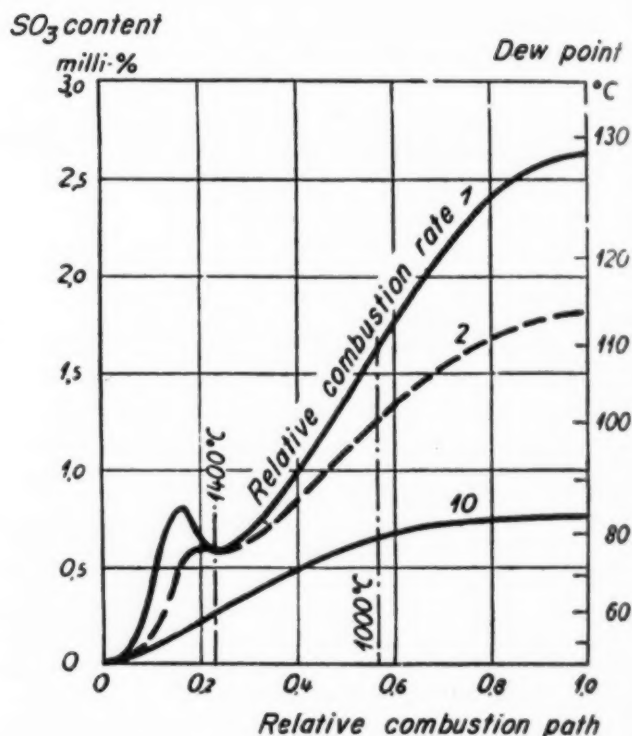


Fig. 3—SO₃ formation in the furnace as a function of the relative path of the flue gas. Different parameters show the dimensionless speeds of reaction

Measurement was made to find out the resistance of reaction of the heterogeneous reaction of charcoal with carbon monoxide. In this case both chemical and physical reactions are present, but as the physical parameters have been changed, the chemical reaction resistance can be computed. It was shown that there is a linear connection between the logarithm of reaction resistance and the logarithm of the absolute temperature. Taking the value 1 for reaction speed at 1000 C, the following resistance of reaction is obtained for other temperatures:

Temperature, deg C.	600	800	1000	1200	1400
Relative resistance of reaction	200	11.5	1	0.12	0.02

The experiment with CO has also been repeated with soda as a catalyst. Here the reaction resistance decreased to one-tenth compared with the case without catalyst.

If the temperature is constant both a and w are constant in equation (4) and it can readily be integrated for steady temperature. The time in the graph, Fig. 1, is given in logarithmic scale. If a horizontal cut is taken we get graphs for different constant values of the reaction time, as shown in Fig. 2. From this it will be seen that the highest SO₃ content is reached at higher and higher temperatures in shorter and shorter times. In the practical case of a steam boiler no constant temperature is available but is variable as the combustion proceeds. It follows that in this case both a and w in equation (4) are variables; but since neither a nor w can be expressed as simple functions of the time or the relative path in the boiler, equation (4) must be integrated in a stepwise successive way or by graphical method. The longer the time of reaction, the lower the reaction speed and the higher the SO₃ function.

Steam Plant Cuts Unit Costs Over Diesel Operation at Menasha

Operation of a new steam power plant, supplanting a combination of diesel-generated and purchased power, has enabled the City of Menasha, Wis., to reduce the cost per kilowatt-hour by more than 25 per cent. Total expenditures went down 6 per cent despite an increase of nearly 26 per cent in production volume.

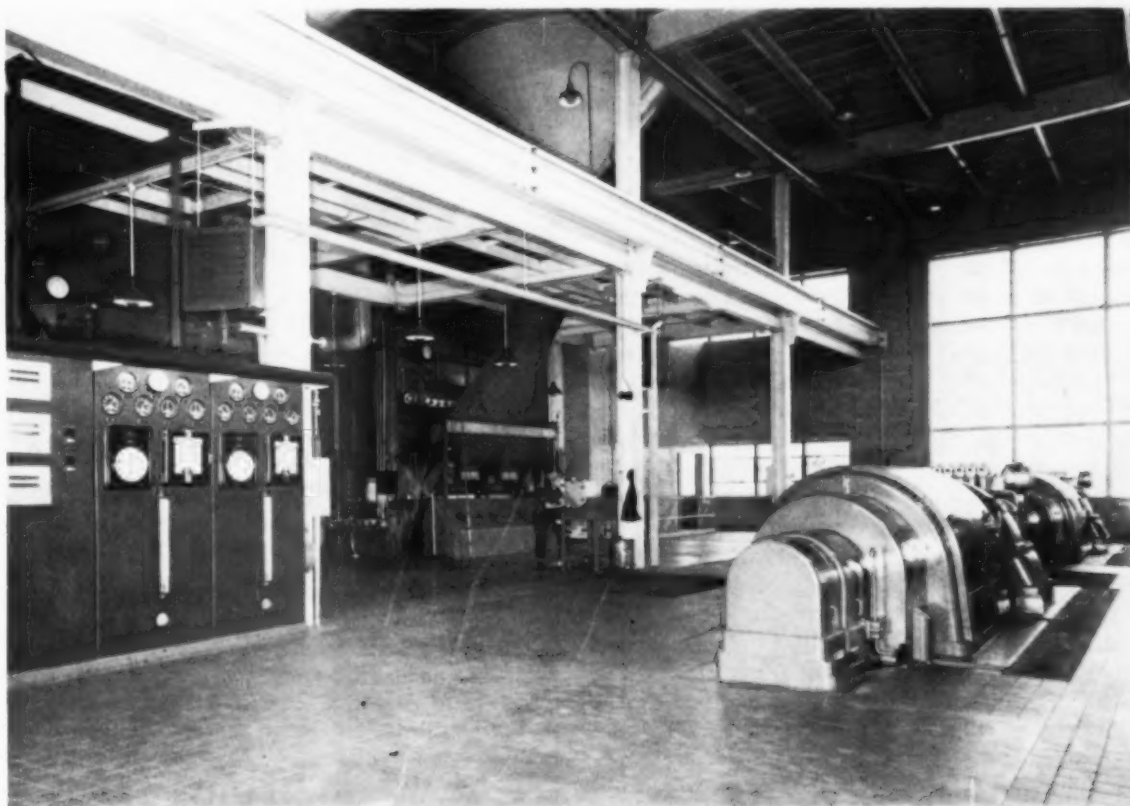
IN 1948, the last full year of operation with diesel generation and purchased power at the Menasha, Wis. municipal plant, 19,812,816 kw-hr was handled at a total cost of \$240,772.67. In 1952, with two 4000-kw steam turbine-generators, one installed in 1949 and the other in 1950, 24,813,600 kw-hr was generated at a total production cost, including an additional 167,700 kw-hr of diesel-generated power, for only \$226,533.16. This represented a 6 per cent reduction in total costs compared with 1948. The cost per kilowatt-hour was cut from 12.13 mills to 9.07 mills, a unit reduction of more than 25 per cent.

By P. E. WIDSTEEN*

First operated as a municipal utility in 1905, the plant originally had three 75-hp diesels, two of which drove triplex pumps for the water system while the third drove a 60-kw generator for the eighty arc lights that constituted the city's electric street-lighting system. It is believed that the pump engines were the first diesels to be used in municipal water service.

By 1930, the plant had grown to where it contained two 600-hp and two 1200-hp engines. The water pumps had since been converted to electric motor drive and the load curve was showing a steady rise. By 1938, the total year's output had reached 9,166,890 kw-hr and in that year a contract was signed with the Wisconsin-Michigan Power Company for purchased power. This was tied into the system through three 1000-kw, 33,000-volt transformers. The municipal plant handled the base load and the public utility handled the peaks.

* Superintendent, Menasha Electric and Water Utilities.



Turbine room with one of the boilers in background

By 1946, further growth of the city increased the total output to 16,360,388 kw-hr, almost double the 1938 total, and the Water and Light Commission hired a firm of consulting engineers to make a detailed study of load conditions and recommend the most practical and economical steps to be taken.

With peak loads approaching the 4000-kw mark and showing no signs of tapering off, the recommendation was to construct a coal-fired steam generating plant with sufficient capacity to handle the entire load. These recommendations were accepted and construction of the new plant was started in July 1948. The first 4000-kw Worthington turbine-generator was placed in operation in November 1949. By this time peak loads had passed the 4000-kw mark and a new peak of 4790 kw was reached just a few days after the first new unit went into service. Therefore a second identical turbine-generator was purchased and put into service early the following year. These are both of the condensing extraction type exhausting at 28 in. vacuum.

Steam is generated in two 60,000 lb per hr spreader-stoker fired boilers operating at 625 psi and 750 F.

Coal is shipped in by rail and dumped from hopper-bottom cars into a track hopper. From the track hopper it is carried by conveyor belt either to the boiler bunkers or to outdoor storage. Handling of the outdoor storage pile is done with a bulldozer which eliminates, through its compacting effect, much of the danger of spontaneous combustion. After reaching the boiler bunkers, the coal drops by gravity to the coal scales and then to the stokers.

Condenser cooling water is taken from nearby Fox River and circulated by a 50-hp, 4000-gpm centrifugal pump. An additional 2500-gpm motor-driven pump and a steam-turbine-driven pump of 1500-gpm capacity are available for light load conditions.

Four stages of feedwater heating are employed. The second stage is a deaerating heater, whereas the first-, third-, and fourth-stage heaters are of the closed shell-and-tube type. Under occasional light load conditions, the first stage is bypassed.

Comparison of Costs

The economies effected with the new plant are clearly shown by a comparison between the years 1948 and 1952 which represent, respectively, the last full year of operation with the combination of diesel and purchased power and the latest full year of operation with the new steam plant. In 1948 the diesel plant produced a net of 10,099,566 kw-hr for a production cost of \$132,422.51. In addition there was purchased a total of 9,713,250 kw-hr at a cost of \$108,350.16. Costs per kilowatt-hour were 13.11 mills and 11.15 mills, respectively, for an average cost of 12.13 mills and a total of \$240,772.67 for 19,812,816 kw-hr.

By contrast, the 1952 total generation was 24,969,300 kw-hr, an increase of 26 per cent but production costs dropped to \$226,533.16, a decrease of 6 per cent. The small total of 155,700 kw-hr that was generated by the diesel engines cost 22.42 mills per kw-hr whereas the kilowatt-hour cost of the steam-generated power was only 8.98 mills. The overall average is 9.07 mills which is a kilowatt-hour cost reduction of 26 per cent from the 1948 figure.

Detailed production expenses for the combined 1948 operations and for the steam operation in 1952 are shown in the tables.

TABLE 1—EXPENSES FOR YEAR ENDING DEC. 31, 1948

PRODUCTION EXPENSES—DIESEL			
Operation, supervision and engineering		\$	3,837.30
Engine labor			13,830.44
Electric labor			81.54
Misc. station labor			1,674.59
Engine fuel			98,622.64
Cooling water			28.08
Lubricants			1,646.69
Station supplies			1,928.89
expenses			526.38
Maintenance—structures and improvements			162.41
—fuel holders			109.82
—engine No. 1			3,650.77
—engine No. 2			5,414.70
—engine No. 3			766.73
—generators			3.49
—accessory electric equipment			58.41
—misc. power plant			79.63
Purchased power			108,350.16
Total production expenses			\$240,772.67

	Kw-hr	Mills per Kw-hr
Net generation	10,099,566	13.11
Purchased power	9,713,250	11.15
Total	19,812,816	12.13
Average Cost		12.13

Total diesel production expense	\$132,422.51
Purchased power	108,350.16
Total production expenses	\$240,772.67

TABLE 2—EXPENSES FOR YEAR ENDING DECEMBER 31, 1952

PRODUCTION EXPENSES—STEAM			
Operation, supervision and engineering			5,500.00
Boiler labor			17,914.78
Prime mover and generator labor			16,790.98
Misc. station labor			6,761.91
Fuel			160,043.53
Water			996.94
Lubricants			125.11
Station supplies			2,346.82
expenses			1,602.85
Maintenance—supervision and engineering			4,824.40
—structures and improvements			96.00
—coal storage and handling eqpt.			1,972.15
—furnace and boiler No. 1			459.39
—" " " No. 2			276.05
—boiler apparatus			1,901.21
—steam piping and accessories			854.03
—prime mover and generator No. 1			90.93
—" " " No. 2			53.73
—misc. power plant equipment			414.76
—accessory electric equipment			16.80
Total production expenses—steam			\$223,042.37
Total production expenses—diesel			\$ 3,491.79
Total			\$226,534.16

	Kw-hr	Mills per Kw-hr
Net generation—steam	24,813,600	8.98
Net generation—diesel	155,700	22.42
Total	24,969,300	9.07
Average Cost		9.07

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High-Pressure Hot Water at Air Bases

Heating with hot water traces back to the Romans, or even earlier; but modern applications of high-temperature hot water for industrial processes and heating have been largely a European development. In such a system, the operating pressure generally corresponds to the saturation temperature. In some installations abroad the heat is imparted by steam through a heat-exchanger and in others by a direct-fired hot-water boiler. The latter practice is followed in this country.

Compared with steam for process or space heating, hot water in a closed system has the advantage of involving very little scale, corrosion or makeup; it does not require traps; the piping system is simpler; and the temperature drop is small.

Basic designs employ closed circuits and water temperatures ranging from 250 to 415 F. The water is heated to

the desired temperature in a hot-water boiler, piped to an expansion drum and then distributed to the load, the pressure in the expansion drum being maintained constant by a steam or air cushion. In one design the water is returned to the boiler for reheating, whereas in a second it is returned to the expansion drum for mixing with the heated water from the boiler. In the latter case an additional pump is required to circulate the water from the expansion drum to the boiler and then back to the drum, whereas one pump suffices in the former design.

A recent interesting application of high-temperature water heating is that which is being employed by the U. S. Corps of Engineers for the Air Force at the Dover, Delaware, Base and at McGuire Base, Wrightstown, New Jersey, for heating aprons and space heating.

The hot-water boilers are of the C-E controlled (forced) circulation type utilizing small diameter tubes with control orifices at the tube inlets. There is a single pass for the combustion gases with minimum draft loss. The tightly welded casing permits pressurized firing with oil. Each unit, of which three are being installed at Dover and four at Wrightstown, is rated at 50 million Btu per hr (corresponding roughly to a 50,000 lb per hr steam boiler) and will operate at 275 psi.

A cross-section of such a unit is shown herewith. From this it will be seen that the furnace, or radiant surface, is completely water cooled with 1½-in. closely spaced side-wall tubes and 2-in. tubes on the front and rear walls. The tubes in the convection section are extensions of the furnace elements. The design can be readily adapted to spreader stoker firing.

It is understood that some forty additional hot-water heating units for various other air bases are contemplated.

New Unit to Employ 4500 Psi and 1150 F

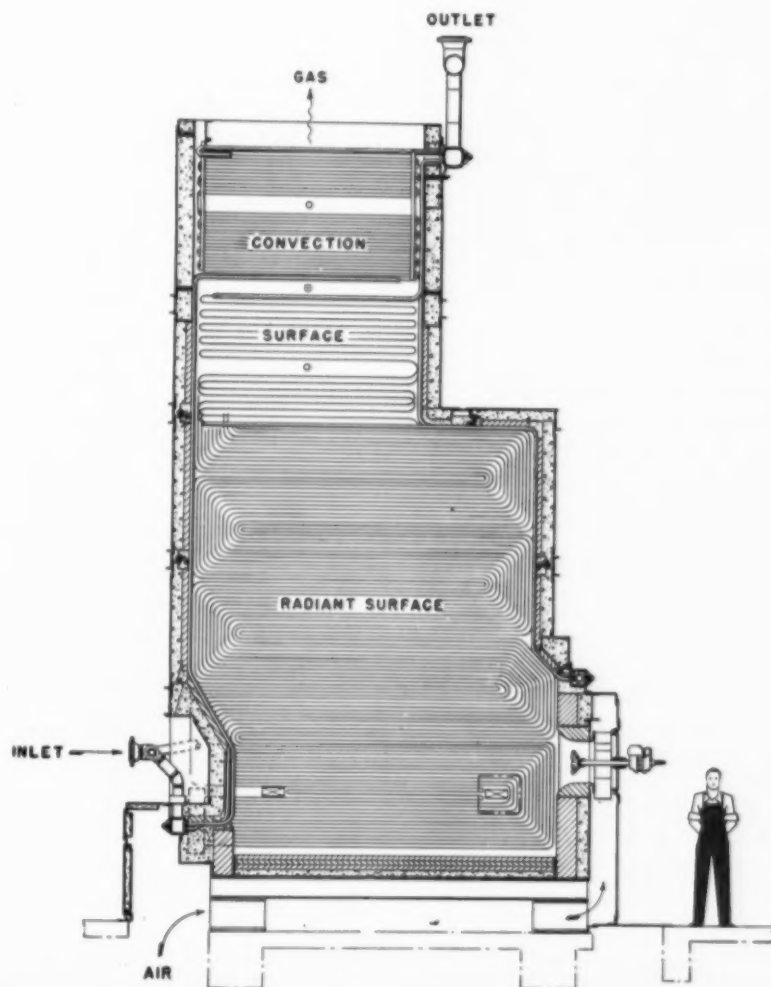
In reporting the 1953 American Power Conference (see April COMBUSTION, page 49) reference was made to a discussion relative to a contemplated 4500-psi, two-stage reheat installation at one of the midwestern central stations. Further details have now been jointly released by the utility and the principal equipment manufacturers concerned, namely, the American Gas and Electric Company, Babcock & Wilcox Company and General Electric Company.

The new installation, of 120,000 kw, will be made at the well-known Philo Station near Zanesville, Ohio, where it will replace a 40,000-kw, 600-psi reheat unit built in 1923.

Steam conditions, as announced, will be 4500 psi, 1150 F and two stages of reheat—the first at 1050 F and the second at 1000 F. This is nearly double the pressure of any unit now in commercial operation, and 50 deg F above the highest steam temperature. Also, it is the first to employ two stages of reheat. In other words, the pressure is well above the "critical" of 3206 psi, beyond which water passes directly into steam without bubbling.

The boiler will be of the once-through type, without a drum, in which the water is pumped in at 5500 psi at one end and comes out as highly superheated steam at the other.

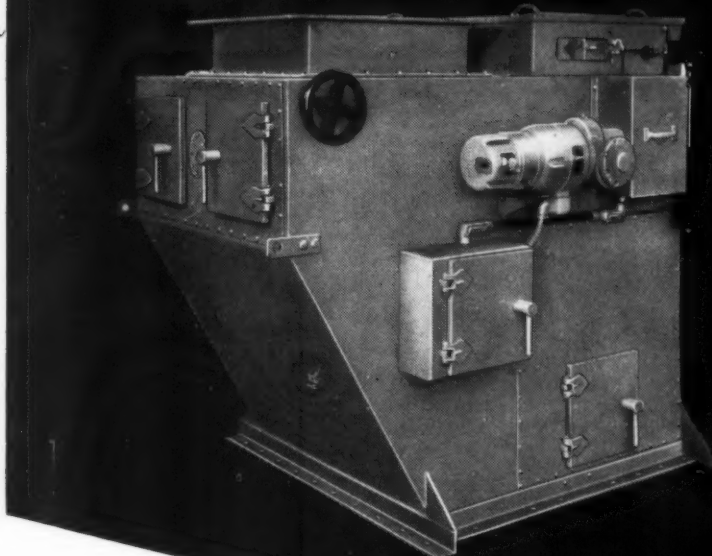
According to Philip Sporn, president of the American Gas and Electric Company, the cost of the project is expected to exceed 12 million dollars. On the basis of the rated capacity this would be around \$100 per kilowatt.



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Battelle Aids Solution of Ireland's Peat-Burning Problem

Improved methods for the production and burning of peat developed by Battelle Institute, Columbus, Ohio, are expected to be of aid to Ireland in the solution of its fuel and power-generation problems.

Technical studies completed by Battelle for the Irish Turf Board, Dublin, have led to recommendations designed to:

- (a) Increase the use of peat and enable Ireland to reduce its imports of coal;
- (b) Decrease the amount of labor needed for the winning of peat; and
- (c) Possibly enable the reduction of the cost of generating electricity.

The research program, arranged by the Economic Cooperation Administration, involved a year of study by Battelle fuel technologists and mechanical engineers. During that time, Ralph Sherman, Battelle assistant director in charge of fuels research, made three trips to Ireland for on-the-spot investigations, and also visited England, France and Germany to survey burning practices and machinery.

According to Mr. Sherman, more than three million acres, or one-sixth of the area of Ireland, are covered by peat bogs. For centuries, peat has been dug from these bogs by hand, dried in the sun in the form of blocks or sods, and laboriously turned, stacked and finally collected for use in cooking, heating and small industry. Even today, this arduous hand labor of thousands of men, women and children accounts for the production of some three-fourths of Ireland's annual production of four to five million tons of peat.

Power Demand Doubles About Every Five Years

With increasing industrialization and the extension of electric service to rural districts, the demand for electricity in Ireland is doubling every five to six years. About half of the installed electric generating capacity is in hydro stations on the Rivers Shannon and Liffey. Up to recently, the remainder was generated in thermal plants using coal imported from England and, at times, at great cost from the United States.

Since the war, the Irish Turf Board has introduced machinery for the winning of sod peat. Mechanization has been so successful that two power plants that burn sod peat are now in operation. However, even the mechanical winning of sod peat requires more manpower than would be available with a future expansion of demand. The

months from March through July that are dry enough for working the bogs are those in which labor is required on the farms.

The Turf Board has also developed milling as a second method of winning peat mechanically. By this method, peat is literally torn from the surface of the bog by spikes mounted on a rapidly whirling drum carried on diesel-powered machines. The fine-milled peat dries rapidly and can quickly be gathered by machines for transportation from the bog. Production per man is more than twice that by mechanical methods of winning sods.

After a study of the problem and a survey of practices in other countries, Battelle recommended the burning of the peat in suspension after pulverization in a German-developed Kraemer-type mill. This recommendation was accepted by the Irish Government, and orders for three boilers for a new station with an initial capacity of 40,000 kw have been placed.

Mechanical engineers at Battelle have also submitted designs of equipment for the mechanical stacking, drying and the collection of sod peat from the surface of the bog. These designs will be studied by Turf Board engineers for incorporation into the machines which they contemplate building.

Testing Boiler Water for Solids

A new test for solids in boiler water, said to be comparable in accuracy and simplicity to the conductometric method, has been developed by Hall Laboratories, Inc., Pittsburgh, consulting engineering firm on water problems. Essentially this test involves mixing the boiler water sample with a strongly alkaline anion-exchange resin, and titrating a portion of the resulting solution with acid to the proper endpoint. A milliequivalent of hydroxide is formed for every milliequivalent of salt in the sample. The volume of standard acid required for the titration, multiplied by a suitable factor, gives an accurate measure of the dissolved solids in the sample.

H. M. Rivers and V. M. Marcy of Hall Laboratories described this method in a paper given before the recent Pittsburgh conference on Analytical Chemistry and Applied Spectroscopy.

Two procedures may be used depending on the degree of accuracy desired. With the "dropper test," which can be made in two minutes, results are reproducible to 200 ppm dissolved solids. The more precise "burette test" requires about three minutes and gives results that are reproducible to within 25 to 50 ppm.

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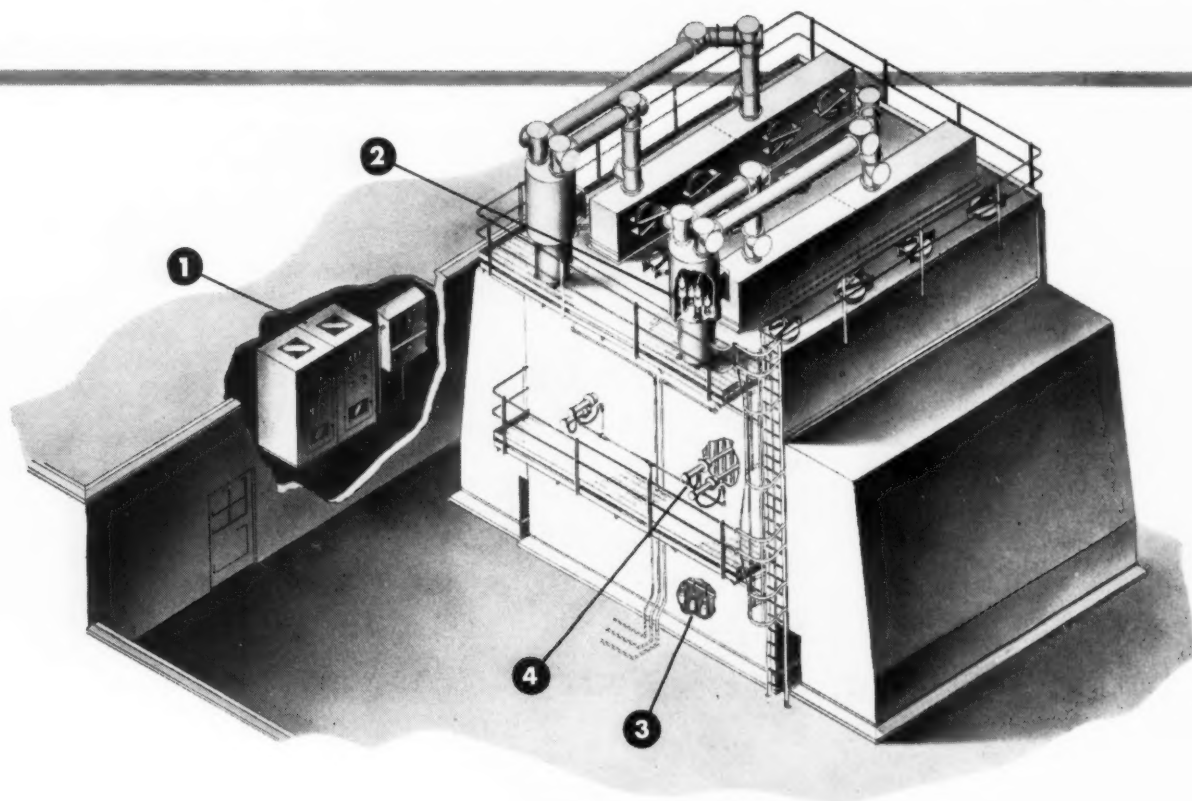
Nalco Bulletin 58 gives basic information on Nalcite HCR, designed to be of sound assistance in designing new softening plants, rebuilding old ones, or simply converting existing facilities for Nalcite HCR high performance. Your copy will be sent free upon request.

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REVIEW OF NEW BOOKS

Any of the books here reviewed may be secured through Combustion Publishing Company, Inc., 200 Madison Ave., N.Y.

American Electricians' Handbook

By Terrell Croft

Revised by Clifford Can

First brought out in 1913, this well-known handbook has gone through seven editions. While the various revisions have maintained the text up to date its practical character has remained unchanged. It is not intended as a textbook nor as a reference for electrical engineers, but rather its aim has been to provide essential information for practical electrical men, small plant operators, contractors, construction engineers, etc. in the selection and installation of commercial electrical equipment. As such, it will be found helpful to many mechanical engineers.

The text contains simple explanations and directions, fully illustrated by numerous sketches, diagrams and curves, as well as tables. The present edition has been made to agree with the 1951 edition of the National Electrical Code.

There are 1773 pages, $4\frac{3}{4} \times 7\frac{1}{4}$ in. and the price is \$10.00.

Basic Mechanics of Fluids

By Hunter Rouse and J. W. Howe

As the title would imply, the treatment is fundamental with the principles of statics, kinematics and dynamics applied to the elementary motion of a fluid, regardless of type.

Both authors are professors at the State University of Iowa and the book was written primarily as a textbook to be covered in the usual semester course. The text should be readily comprehended outside the classroom and should serve as a ready reference for those confronted with problems involving flow patterns, pressure-velocity relationships flow in pipes, conducts, etc.

There are 245 pages, well illustrated. With conventional cloth binding; the price is \$4.50.

Atomic Power

By Walter Isard and Vincent Whitney

A good grasp of the scope of this book can be obtained from its two subtitles, "An Economic and Social Analysis" and "A Study in Industrial Location and Regional Economic Development." Dr. Isard, who lectures in economics at Harvard University, and Dr. Whitney,

who teaches sociology at Brown University, have approached the subject of atomic power from an unusually broad point of view. They have taken into consideration sociological, political and geographical factors in attempting to assess the potential overall impact of atomic developments.

In a well-written introductory chapter the authors present the technical background of nuclear energy, noting that it represents a valuable increment to existing energy resources. A chapter entitled "The Costs of Atomic Power" is more valuable for the techniques of comparison set forth than for the cost data supplied. This statement is indicative of the position of the authors: "The real comparison may well be not between the atomic plant and the conventional steam station but between two integrated systems, one made up entirely of conventional steam stations and the other composed of a base-load atomic station and of coal plants specially designed to handle peak loads."

Subsequent chapters take up the problems relating to the location of atomic power plants, with special reference to quantities of power required by various industries. Specific case studies are based upon possible applications in the steel and aluminum industries. Another section of the book is given over to regional applications in countries that are underdeveloped in an economic sense. A concluding chapter deals with the probable future prospects of atomic power.

The real merit of this 236-page book, which sells for \$4.75, is that it attempts to look beyond strictly technical problems to the broader economic, sociological and political ramifications of atomic energy.

Engineers As Writers

Edited by Walter J. Miller
and Leo E. A. Saidla

Seldom does one pick up a textbook which, apart from professional content, affords the enjoyment of pleasurable reading. But Professors Miller and Saidla of the Department of English of the Polytechnic Institute of Brooklyn have succeeded in selecting and weaving together fifteen excerpts from the writings of engineers so that the reader

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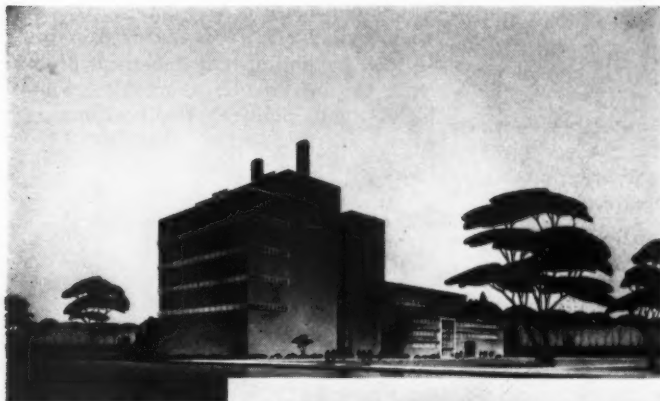
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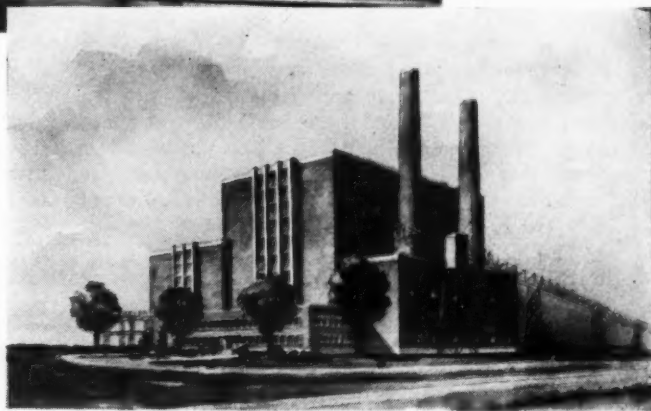
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Each of the excerpts is preceded and followed by a commentary which tells something of the author, of the time and circumstance in which the piece was written and of the style and techniques used. These commentaries add much to the value of what the authors correctly term "a pioneer work of an interdisciplinary nature." Although intended as a text for motivating student engineers to learn to write through study of the structure and style of engineering literature, it is to be hoped that this book will find a much wider audience among practicing engineers. Actually it expresses a universality of interests and a common ground of techniques shared by all engineers.

There are many who will agree with the authors that students can, before attempting engineering writing of their own, appreciate the problems of engineering readers and "see for themselves that there is an organized and respected body of engineering literature, that there is a proud tradition of writing it, and that they have certain literary standards to live up to if they are to be competent engineers."

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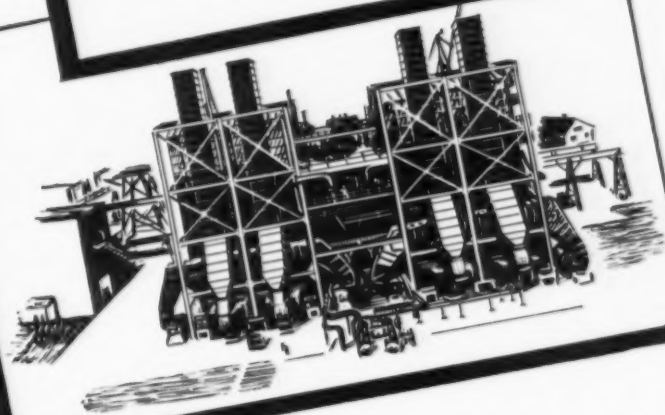
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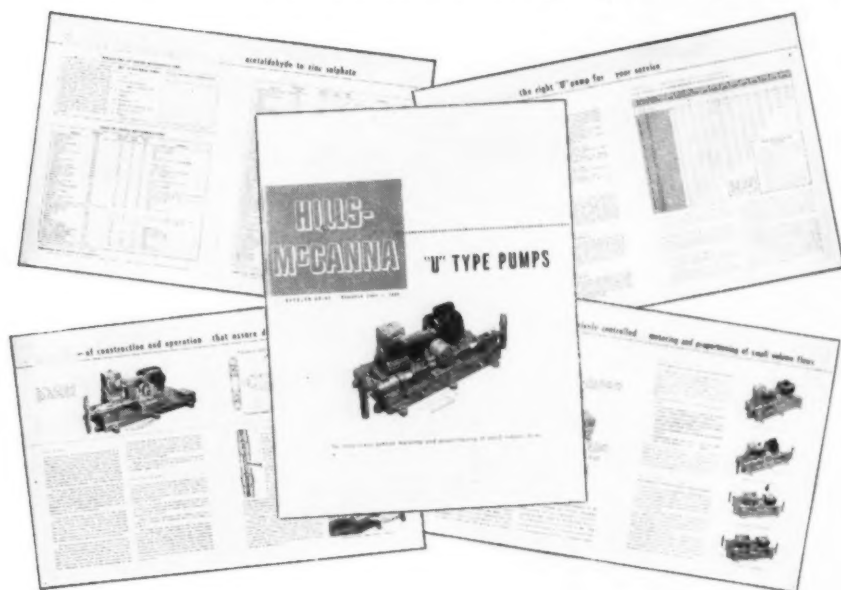
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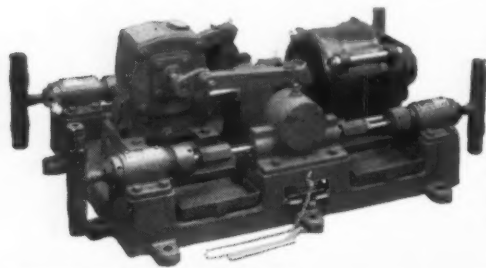
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Diatomite

An attractive 28-page brochure, "Celite, The Story of Diatomite," has been published by Johns-Manville. The first section tells what a diatom is and explains how these marine organisms emerged as a unique deposit in California. The next section deals with the discovery of the deposit, and succeeding sections describe the current benefits of diatomite as filter powder for water purification, as a mineral filler in the manufacture of paint, and as high-temperature insulation.

Zeolite Water Softeners

Bulletin WC-108 prepared by the Graver Water Conditioning Co. explains the distinction between the sodium cycle and the hydrogen cycle of zeolite softening and graphically shows the differences in results obtained by the two processes. This fundamental discussion is followed by a description of the design and operation of equipment used in zeolite water softening and regenerating processes. A final section of this 12-page brochure contains an outline of a simple method for sizing zeolite softeners, including a table of recommended flow rates.

Laboratory Apparatus

A four-page bulletin has been made available by the Burrell Corp. and describes, illustrates and lists prices for gas analyzers, laboratory furnaces, and induction heaters.

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General and Classified Index

COMBUSTION, Volume Twenty-Four, July 1952 Through June 1953

EDITORIALS

	PAGE
Another Italian Power Station.....	Sept. 1952 35
Art of the Practical Engineer, The.....	Feb. 1953 39
Better Utilization of Engineers Advocated.....	Sept. 1952 35
Beyond the Call of Duty.....	Dec. 1952 37
Common Sense—A Redefinition.....	Jan. 1953 35
Davis, Dr. Harvey N.....	Dec. 1952 37
Establishing Authorship.....	Aug. 1952 39
Evaluating Experimental Data.....	Jan. 1953 35
External Tube Corrosion.....	June 1953 39
For Your "Must" Reading List.....	June 1953 39
From Steel to Coal.....	Aug. 1952 39
Government Projects Will Require Vast Coal Tonnage.....	May 1953 39
Important Survey, An.....	Jan. 1953 35
Industry Aid to Education.....	Aug. 1952 39
In Recognition of "Extraordinary Efficiency".....	July 1952 31
International Steam Table Conferences.....	Mar. 1953 35
Large Meeting Presents Problems.....	Dec. 1952 37
Men, Machines and Economics.....	Mar. 1953 35
New Preferred Standards.....	Feb. 1953 39
Puff vs. Explosion.....	May 1953 39
Restricted Information.....	July 1952 31
Return to Fundamentals, A.....	Nov. 1952 37
Selling an Industry to Young Engineers.....	Apr. 1953 39
Status of Nuclear Power.....	Oct. 1952 39
Steam-Electric Utility Survey.....	Nov. 1952 37
Tavazzano Recalls an Historic Event.....	July 1952 31
Wanted: A Centripetal Professional Force.....	June 1953 39
We Have Just Begun to Dream.....	Oct. 1952 39
What Is Readable Technical Writing?.....	Apr. 1953 39
When Does a Prime Mover Become "Conventional"?.....	May 1953 39
When is "Big" Too Big?.....	Sept. 1952 35

ARTICLES

Acid Regeneration of Cation Exchangers, <i>American Power Conference</i> . By F. K. Lindsay.....	Apr. 1953 53
Additives to Fuel Oil, Part I, <i>ASME Annual Meeting</i> . By J. B. McIlroy and E. J. Holler, Jr.....	Dec. 1952 62
Additives to Fuel Oil, Part II, <i>ASME Annual Meeting</i> . By R. Lee.....	Dec. 1952 62
Advances in Synthetic Fuels Technology.....	Feb. 1953 66
Air Pollution Symposium, <i>ASME Annual Meeting</i> : Dr. Robert A. Kehoe, P. W. Zimmerman, E. Wendell Hewson, George F. Jenkins and Leslie Silverman.....	Dec. 1952 65
Air Preheater Design as Affected by Fuel Characteristics, <i>ASME Annual Meeting</i> . By Hilmer Karlsson and William Hammond.....	Dec. 1952 59
AIEE Winter General Meeting—Engineering Training, <i>Air Pollution Prevention, Controllability of Central Stations, Interconnected Power Systems and Nuclear Power Plants</i>	Feb. 1953 61
American Power Conference Program.....	Mar. 1953 59
ASME-AIME Holds Joint Meeting.....	Nov. 1952 65
ASME Annual Meeting Program Briefed.....	Nov. 1952 59
ASME Spring Meeting Program.....	Apr. 1953 65
Application and Performance of Single-Retort Underfeed Stokers, <i>ASME Annual Meeting</i> . By E. C. Webb and J. E. Atchinson.....	Dec. 1952 58
Application of Metallic Phosphates to Cooling Water Treatment, <i>Thirteenth Annual Water Conference</i> . By William J. Stone.....	Nov. 1952 55
Are Federal Power Practices Sound National Policy? <i>American Power Conference</i> . By E. R. de Luccia.....	Apr. 1953 54
Beckjord Station Dedicated.....	July 1952 45
Boiler Construction Costs. By Herman Weisberg.....	Feb. 1953 45
Boiler Controls for Multiple Fuels, <i>ASME Fall Meeting</i> . By A. C. Wenzel.....	Oct. 1952 43
Bokaro Placed in Service.....	Mar. 1953 64
Breaker Bars for Traveling Grate Stokers. By Walter Greacen III.....	Nov. 1952 43
Burning Pulverized Cinders, <i>ASME Spring Meeting</i> . By John M. Allen.....	May 1953 59
Central Station Construction Costs, <i>ASME Annual Meeting</i> . Panel Discussion: Arthur Larnard, Herman Weisberg, E. H. Krieg, H. A. Wagner and R. W. Parkinson.....	Dec. 1952 55
Century of Engineering Progress Marked by Chicago Meeting.....	Oct. 1952 40
Chemical Cleaning in Central Stations, <i>ASME Spring Meeting</i> . By P. H. Cardwell.....	May 1953 55
Cincinnati Host to ASME Semi-Annual Meeting.....	July 1952 37
Classification of Outages of Facilities in Electric Power Systems, A. By Arnold Rich.....	Mar. 1953 43
Combustion of Pulverized Coal in a Water-Cooled Radiant Tube, <i>ASME Annual Meeting</i> . By Ralph A. Sherman, Gerald E. Keinath and R. Tom Sawyer.....	Dec. 1952 65
Condensate Contamination, <i>ASME Annual Meeting</i> . By J. D. Ristorph and E. B. Powell.....	Dec. 1952 63
Control of Resinous Materials in Low-Pressure Boilers,	

<i>Thirteenth Annual Water Conference</i> . By W. L. Andrews.....	Nov. 1952 56
Conversion of a Two-Stage Hot Process Water Softener from Hot Lime-Soda Phosphate to Hot Lime Zeolite at Cambridge Electric Light Co., <i>ASME Annual Meeting</i> . By G. H. Gowdy and S. B. Applebaum.....	Dec. 1952 63
Cooling Towers, <i>Thirteenth Annual Water Conference</i> . Panel Discussion: J. S. Hill, R. S. Wise, George Illig, J. F. Wilkes and J. K. Rice.....	Nov. 1952 55
Corrosion of Mercury Boiler Tubes During Combustion of a Heavy Residual Oil, <i>ASME Annual Meeting</i> . By A. M. Hall, D. Douglass and J. H. Jackson.....	Dec. 1952 62
Creep in Steels for Steam Power Plants. By A. M. Sage.....	Apr. 1953 63
Cross Compound Designs, <i>American Power Conference</i> . By Charles D. Wilson.....	Apr. 1953 49
Dechy Power Plant at Sin-Le-Noble, Nord France. By S. Weiner and E. Aslaksen.....	Dec. 1952 38
Deionization vs. Evaporation of Hard Water Supplies for Boiler Makeup, <i>Thirteenth Annual Water Conference</i> . By T. C. Hoppe and R. A. Russell.....	Nov. 1952 54
Demineralizing Experience, <i>ASME Fall Meeting</i> . By V. B. Burgess and D. N. Purcell.....	Oct. 1952 46
Design and Application of Large Steam Turbines, <i>American Power Conference</i> . By Carl Schabtach, C. E. Kilbourne and J. B. McClure.....	Apr. 1953 48
Design and Performance of Liquid-Metal Heat-Exchangers and Steam Generators for Nuclear Power Plants, <i>ASME Annual Meeting</i> . By R. D. Brooks and A. L. Rosenblatt.....	Dec. 1952 58
Design for Extreme Flood Conditions at the Paddy's Run Station, <i>ASME Semi-Annual Meeting</i> . By D. C. Hormell.....	July 1952 39
Development of High-Output Free-Piston Gas Generators, <i>ASME Spring Meeting</i> . By Frank M. Lewis and Robert A. Lasley.....	May 1953 54
Development of Improvements in Boiler Water Level Gages. By Frank Ptacek.....	Oct. 1952 56
Development of the 3600-rpm Turbine, <i>American Power Conference</i> . By H. R. Reese.....	Apr. 1953 48
District Heating, <i>Century of Engineering</i> . By A. R. Mumford.....	Oct. 1952 41
Dust Emissions from Small Spreader-Stoker-Fired Boilers, <i>ASME Spring Meeting</i> . By E. J. Boer and W. Porterfield.....	May 1953 58
Economical Industrial Power Plant Design, <i>ASME Annual Meeting</i> . By C. S. Robinson.....	Dec. 1952 55
Economics, the Key to Evaporation Vs. Demineralization for Makeup in High-Pressure Steam Power Plants, <i>American Power Conference</i> . By E. B. Morris and C. E. Brune.....	Apr. 1953 53
Effect of Operating Pressure on Carbon Dioxide Content of Steam, <i>Thirteenth Annual Water Conference</i> . By J. J. Maguire and R. E. Winston.....	Nov. 1952 56
Effects of Temperature on Steam Turbine Oil. By Thomas L. Byrne.....	May 1953 45
Elastic-Fluid Centripetal Turbine for High Specific Outputs, <i>ASME Spring Meeting</i> . By Rudolph Birman.....	May 1953 55
Electrostatic Precipitators. By H. J. White.....	Mar. 1953 49
Engineering and Technical Problems of Atomic Power. By Walter H. Zinn.....	June 1953 49
Engineering Economy in the Electric Utility Industry. By K. M. Irwin.....	Sept. 1952 53
Experience with Amines, <i>American Power Conference</i> . By H. J. Guillery.....	Apr. 1953 53
Experiences with Application of Deaerating Heaters in Feedwater Cycles, <i>Thirteenth Annual Water Conference</i> . By V. J. Calise and R. K. Stenard.....	Nov. 1952 54
Experience with Large Generating Units, <i>American Power Conference</i> . By R. P. Liversidge.....	Apr. 1953 47
Experiences with Chloride Anion Exchangers for Reducing Alkalinity Without Acid, <i>Thirteenth Annual Water Conference</i> . By S. B. Applebaum.....	Nov. 1952 53
Experience with Furnace Television. By L. M. Exley.....	Nov. 1952 63
Expert Sees Economic Atomic Power 10 to 15 Years Off.....	May 1953 60
External Boiler Tube Deposits. By H. E. Crossley.....	Oct. 1952 61
Feedwater Conditioning by Evaporation, <i>American Power Conference</i> . By A. M. Impagliazzo.....	Apr. 1953 52
Fernand Courtoy Power Station at Awirs, Liege, The. By Baron A. Forgeur.....	Aug. 1952 40
Fiber Glass Plant Employs Automatic Steam Generators.....	Mar. 1953 70
Free-Piston Type of Gas-Turbine Plant and Applications, The, <i>ASME Spring Meeting</i> . By J. J. McMullen and Robert P. Ramsey.....	May 1953 53
Furnace-Heat Absorption Efficiency as Shown by Enthalpy of Gases Leaving the Furnace, <i>ASME Annual Meeting</i> . By J. W. Myers and R. C. Corey.....	Dec. 1952 56
Future of Steam and Electric Power, <i>Century of Engineering</i> . By Theodore Baumeister.....	Oct. 1952 41

	PAGE		PAGE
Gas Turbines and Centrifugal Compressors for Natural Gas Pipelines, <i>ASME Annual Meeting</i> . By T. R. Rhea and J. S. Quill.	Dec. 1952 64	Process for Utilizing Western Lignite.	May 1953 61
Greenwich Steam Generating Station of Atlantic City Electric Co. By V. J. Feeney.	Apr. 1953 40	Progress and Future Trends in Electric Transmission, <i>Century of Engineering</i> . By S. B. Cary, I. W. Gross and C. F. Wagner.	Oct. 1952 12
Handling Material for the Walter C. Beckjord Station. By Raymond F. Schierland.	Aug. 1952 51	Pumps for Handling Liquid Metals, <i>ASME Annual Meeting</i> . By Philip M. Clark and J. F. Cage, Jr.	Dec. 1952 58
Heard at the ASME Annual Meeting.	Dec. 1952 53	Quick Starting of Large High-Pressure, High-Temperature Boilers, <i>ASME Annual Meeting</i> . By J. C. Falkner.	Dec. 1952 53
High Pressure Hot Water at Air Bases.	June 1953 57	Quick Starting of Turbines, <i>ASME Annual Meeting</i> . By C. W. Elston.	Dec. 1952 54
Improved Utilization of Waste Heat. By Dr. Richard Dolezal.	Sept. 1952 57	Reading Modernizes Its Power Plant. By B. R. Wheelock, Jr.	Nov. 1952 38
Industrial Applications of Nuclear Energy, <i>ASME Fall Meeting</i> . By Alfonso Tammaro.	Oct. 1952 47	Relation of Spreader Stokers to Air Pollution. By Max O. Funk.	July 1952 41
Industrial Power Construction Costs, <i>ASME Annual Meeting</i> . By F. G. Feeley, Jr.	Dec. 1952 56	Removal of Oil from Condensate by Diatomite Filtration, <i>Thirtieth Annual Water Conference</i> . By G. R. Bell.	Nov. 1952 56
Industrial Power Plant Construction Costs. By T. A. Fearnside and F. C. Cheney.	Jan. 1953 47	Residual Fuel Oil Ash Corrosion, <i>ASME Annual Meeting</i> . By B. O. Buckland, C. M. Gardiner and D. G. Sanders.	Dec. 1952 61
Industrial Power Plant Operation, <i>American Power Conference</i> : Wyle Austin (Paper Mill); L. E. Joslin (Packing House); C. R. Bender (Hospital); Sal Gran (Penal Institution).	Apr. 1953 52	Residual Fuel Oils in Gas Turbines, <i>ASME Annual Meeting</i> . By Philip Draper.	Dec. 1952 62
Influence of Low Quality Coal on Pulverized-Fuel-Fired Units. By Otto de Lorenzi.	Nov. 1952 46	Prime Mover Advances Feature ASME Spring Meeting—Free-Piston Gas Generators, Centripetal Turbines, Chemical Cleaning in Central Stations, Oxygen Solubility, Overfire Air, Mill Drying of Coal, Spreader Stoker Dust Emission, Estimating Smoke Density and Burning Pulverized Cinders.	May 1953 53
Inner-Cooled Turbine-Generators, <i>American Power Conference</i> . By J. W. Batchelor.	Apr. 1953 50	Residual Fuel Oils in Gas Turbines, <i>ASME Annual Meeting</i> . By Philip Draper.	Dec. 1952 62
Instrumentation for Detection of Stack Emissions. By Gordon R. Hahn.	Dec. 1952 67	Resistance of Cast Fe-Cr-Ni Alloys to Corrosion in Oxidizing and Reducing Flue-Gas Atmospheres, <i>ASME Annual Meeting</i> . By J. H. Jackson, C. J. Slunder, O. H. Harder and J. T. Gow.	Dec. 1952 61
Investment Costs—Industrial Power Plants, <i>ASME Annual Meeting</i> . By John Campbell.	Dec. 1952 56	Series Dust-Collector Installations on Large Pulverized Coal Boilers. By L. W. Cadwallader.	Aug. 1952 47
Kyrene Steam Plant Designed for Southwest Conditions. By T. M. Morong, I. R. Caraco and E. J. Laueran.	Oct. 1952 48	Smokescope, The—An Instrument for Estimating the Density of Smoke in Stack Effluent, <i>ASME Spring Meeting</i> . By John P. Strange.	May 1953 58
Liquid Metal as a Heat Transfer Medium, <i>ASME Annual Meeting</i> . By Thomas Trocki and D. B. Nelson.	Dec. 1952 57	Solubility of Oxygen in Water, The, <i>ASME Spring Meeting</i> . By L. M. Zoss, S. Suciu and W. L. Sibbitt.	May 1953 56
Local Carbide Segregation and Decarburization in Welded Joints. By H. S. Blumberg and I. A. Rohrig.	Mar. 1953 36	Some Practical Aspects of Combustion in the Gas Turbine, <i>American Power Conference</i> . By Herbert R. Hazard.	Apr. 1953 56
Material Handling Facilities, Walter C. Beckjord Station, Cincinnati Gas & Electric Co., <i>ASME Semi-Annual Meeting</i> . By Raymond F. Schierland.	July 1952 40	Some Theoretical Aspects of Centripetal Turbines, <i>ASME Spring Meeting</i> . By Richard L. Robinson.	May 1953 55
Materials Situation, The, <i>American Power Conference</i> . By J. F. Moore.	Apr. 1953 54	South Texas Outdoor Power Stations, <i>ASME Fall Meeting</i> . By Harry G. Hiebler.	Oct. 1952 44
Mechanical Engineers to Participate in Century of Engineering.	Aug. 1952 57	Steam and Electric Power—Its Past and Future. By Theodore Baumeister.	Dec. 1952 45
Metals and Metal Processing in the Atomic Energy Field. By Alan U. Seybolt.	July 1952 47	Steam Plant Cuts Unit Cost Over Diesel Operation at Menasha. By P. E. Widsten.	June 1953 59
Meteorological Aspects of Air Pollution Control. By O. K. Anderson.	Jan. 1953 52	Steel Works Power Plants, <i>ASME Fall Meeting</i> . By Robert W. Worley and Harold J. Benton.	Oct. 1952 44
Milesburg Power Station, <i>ASME Semi-Annual Meeting</i> . By W. V. Drake and R. A. Mycoff.	July 1952 39	Study of Reducing Solutions at Steam Boiler Temperatures, A. By Harry D. Ongman.	Feb. 1953 40
Mill Drying in Pulverizing High-Moisture Coals, <i>ASME Spring Meeting</i> . By Wayne C. Rogers.	May 1953 57	Sulfur Trioxide in Flue Gases. By S. Juhasz.	June 1953 53
Minimum Continuous Safe Flow of Centrifugal Pumps. The. By E. C. Condict.	Aug. 1952 55	Superheater Tube Temperature Measurements. By T. W. Jenkins, Jr.	Apr. 1953 59
Modern Steam Plant at Villanova College.	Sept. 1952 50	Superheater Tubing Materials for High Temperatures, <i>ASME Annual Meeting</i> . By C. J. Slunder, A. M. Hall and J. H. Jackson.	Dec. 1952 60
New Features of Steam Plants on Inland Rivers, <i>ASME Semi-Annual Meeting</i> . By G. V. Williamson.	July 1952 39	Thermal Shock and Other Comparison Tests of Austenitic and Ferritic Steels for Main Steam Piping, <i>ASME Annual Meeting</i> . By W. C. Stewart and W. G. Schreitz.	Dec. 1952 63
New Italian Power Station Operates at 1850 Psig. By Dr. Claudio Castellani.	July 1952 32	Thirtieth Annual Water Conference.	Nov. 1952 53
New Kearny Station in Service.	May 1953 40	3,000,000 Kw Operating Experience with Modern Reheat. By Otto de Lorenzi.	May 1953 47
New Steam Table Up to 700 C. By Dip. Ing. H. Erythropel.	Mar. 1953 55	Topographical Influences on Dispersal of Stack Gases. By Gordon H. Strom and James Halitsky.	June 1953 40
1953 American Power Conference, The.	Apr. 1953 47	Training Power Plant Personnel, A Symposium, <i>ASME Semi-Annual Meeting</i> : F. E. Nicolson, J. D. Williamson, Albert H. Beiler, John E. Geue, D. F. Steinke and Vern L. Stone.	July 1952 37
Nuclear Power Symposium, <i>American Power Conference</i> : Louis C. McCabe, W. L. Davidson, Walter H. Zinn, Walker L. Cislser and O. M. Reubhausen.	Apr. 1953 55	Trends in Combustion and Steam Temperature Control, <i>American Power Conference</i> . By P. S. Dickey.	Apr. 1953 51
Operating Spreader Stokers. By Leo J. Cohan.	Oct. 1952 64	Tubular Air Heater Problems, <i>ASME Annual Meeting</i> . By E. F. Rothemich and G. Parmakian.	Dec. 1952 60
Optimum Design for Surface Condensers, <i>ASME Fall Meeting</i> . By James T. Fong.	Oct. 1952 46	Turbulent Suspension Burning. By Otto de Lorenzi.	Oct. 1952 55
Overfire Air Installation at the Conners Creek Power Plant, <i>ASME Spring Meeting</i> . By James W. Campbell and Richard J. Travis.	May 1953 56	Units for Joppa.	Oct. 1952 55
Past Progress and Present Trends in the Art of Power Generation, <i>Century of Engineering</i> . By A. C. Monteith and A. A. Johnson.	Oct. 1952 41	Use of Pellets for Slag Removal, <i>ASME Annual Meeting</i> . By W. F. Cantieri.	Dec. 1952 64
Performance of Free-Piston Gas Generators, <i>ASME Spring Meeting</i> . By J. J. McMullen and Warren Payne.	May 1953 54	Utilization of Low-Grade Coals for Power Generation. By Richard C. Corey and James W. Myers.	Sept. 1952 43
Piacenza Station of the Societa Edison. By Dott. Ing. Franco Castelli.	Sept. 1952 36	Variation in Furnace Heat-Absorption as Shown by Measurement of Temperature of Exposed Side of Furnace Tubes, <i>ASME Annual Meeting</i> . By F. G. Feeley, Jr., and Earle C. Miller.	Dec. 1952 57
Power Activity in 1952.	Jan. 1953 43	Vorticity Heat Transfer in Molten Metals, <i>ASME Annual Meeting</i> . By R. A. Kennison.	Dec. 1952 58
Power and Steam Generation at Chillicothe Division of The Mead Corporation. By Walter H. Hall.	Jan. 1953 36	Wood Burning in a Central Station (City of Eugene, Ore.), <i>ASME Annual Meeting</i> . By R. B. Boals, Dale Bumstead, Jr., and C. J. Judson.	Dec. 1952 59
Power Expansion at Nekoosa-Edwards Paper Co. By Frank H. Coldwell.	Feb. 1953 49		
Preheating Combustion Air by Extracted Steam. By S. Bente.	Jan. 1953 57		
Preparing Steam Generating Unit for Service at O. H. Hutchings Station. By R. E. Novak.	June 1953 45		
Present-Day Thoughts on the Application of Single-Retort Underfired Stokers, <i>ASME Annual Meeting</i> . By D. J. Mosshart.	Dec. 1952 58		
Present Status of Supercharged Cooling, <i>American Power Conference</i> . By W. L. Ringland and L. T. Rosenberg.	Apr. 1953 49		
Pressure Operation, <i>ASME Fall Meeting</i> . By G. W. Bice and W. M. Yeknik.	Oct. 1952 45		
Prevention of Metal Losses in the Wet Steam Areas of Steam Turbines, <i>American Power Conference</i> . By F. L. Archibald, J. W. Purcell, Jr., and F. G. Straub.	Apr. 1953 51		

AUTHORS

Allen, John M.— <i>Burning Pulverized Cinders</i> , <i>ASME Spring Meeting</i>	May 1953 59
Anderson, O. K.— <i>Meteorological Aspects of Air Pollution</i>	

		PAGE
61	Control.....	Jan. 1953 52
12	Andrews, W. L.—Control of Resinous Materials in Low-Pressure Boilers, Thirteenth Annual Water Conference.....	Nov. 1952 56
38	Applebaum, S. B.—Experiences with Chloride Anion Exchangers for Reducing Alkalinity without Acid, Thirteenth Annual Water Conference.....	Nov. 1952 53
53	Applebaum, S. B., and G. H. Gowdy—Conversion of a Two-Stage Hot Process Water Softener from Hot Lime-Soda Phosphate to Hot Lime Zeolite at Cambridge Electric Light Co., ASME Annual Meeting.....	Dec. 1952 63
54	Archibald, F. L., J. W. Pursell, Jr., and F. G. Straub—Prevention of Metal Losses in the Wet Steam Areas of Steam Turbines, American Power Conference.....	Apr. 1953 51
11	Aslaksen, E., and S. Weiner—Dechy Power Plant at Sin-Le-Noble, Nord France.....	Dec. 1952 38
56	Atchinson, J. E., and E. C. Webb—Application and Performance of Single-Retort Underfeed Stokers, ASME Annual Meeting.....	Dec. 1952 58
61	Austin, Wyle—Industrial Power Plant Operation (Paper Mill), American Power Conference.....	Apr. 1953 52
62	Batchelor, J. W.—Inner-Cooled Turbine-Generators, American Power Conference.....	Apr. 1953 50
	Baumeister, Theodore, Jr.—Steam and Electric Power—Its Past and Future.....	Dec. 1952 45
53	Beiler, Albert H., F. E. Nicoson, J. D. Williamson, John E. Geue, D. F. Steinke and Vern L. Stone—Training Power Plant Personnel, A Symposium, ASME Semi-Annual Meeting.....	July 1952 38
62	Bell, G. R.—Removal of Oil from Condensate by Diatomite Filtration, Thirteenth Annual Water Conference.....	Nov. 1952 56
	Bender, C. R.—Industrial Power Plant Operation (Hospital), American Power Conference.....	Apr. 1953 52
61	Bente, S.—Preheating Combustion Air by Extracted Steam.....	Jan. 1953 57
47	Bentson, Harold J., and Robert W. Worley—Steel Works Power Plants, ASME Fall Meeting.....	Oct. 1952 44
58	Bice, G. W., and W. M. Yeknik—Pressure Operation, ASME Fall Meeting.....	Oct. 1952 45
56	Birmann, Rudolph—The Elastic-Fluid Centripetal Turbine for High Specific Outputs, ASME Spring Meeting.....	May 1953 55
56	Blumberg, H. S., and I. A. Rohrig—Local Carbide Segregation and Decarburization in Welded Joints.....	Mar. 1953 36
55	Boals, R. B., Dale Bumstead, Jr., and C. J. Judson—Wood Burning in a Central Station (City of Eugene, Ore.), ASME Annual Meeting.....	Dec. 1952 59
44	Boer, E. J., and C. W. Porterfield—Dust Emissions from Small Spreader-Stoker-Fired Boilers, ASME Spring Meeting.....	May 1953 58
45	Brooks, R. D., and A. L. Rosenblatt—Design and Performance of Liquid-Metal Heat-Exchangers and Steam Generators for Nuclear Power Plants, ASME Annual Meeting.....	Dec. 1952 58
59	Brune, C. E., and E. B. Morris—Economics, the Key to Ecoporation Vs. Demineralization for Makeup in High-Pressure Steam Power Plants.....	Apr. 1953 53
40	Buckland, B. O., C. M. Gardiner and D. G. Sanders—Residual Fuel Oil Ash Corrosion, ASME Annual Meeting.....	Dec. 1952 61
59	Bumstead, Dale, R. B. Boals and C. J. Judson—Wood Burning in a Central Station (City of Eugene, Ore.), ASME Annual Meeting.....	Dec. 1952 59
60	Burgess, V. B., and D. N. Purcell—Demineralizing Experience, ASME Fall Meeting.....	Oct. 1952 46
63	Byrne, Thomas L.—Effects of Temperature on Steam Turbine Oil.....	May 1953 45
53	Cadwallader, L. W.—Series Dust-Collector Installations on Large Pulverized Coal Boilers.....	Aug. 1952 47
47	Cage, J. R., Jr., and Philip M. Clark—Pumps for Handling Liquid Metals, ASME Annual Meeting.....	Dec. 1952 58
40	Calise, V. J., and R. K. Stenard—Experiences with Application of Deaerating Heaters in Feedwater Cycles, Thirteenth Annual Water Conference.....	Nov. 1952 54
37	Campbell, James W., and Richard J. Travis—Overfire Air Installation at the Conners Creek Power Plant, ASME Spring Meeting.....	May 1953 56
51	Campbell, John—Investment Costs—Industrial Power Plants, ASME Annual Meeting.....	Dec. 1952 56
60	Cantieri, W. F.—Use of Pellets for Slag Removal, ASME Annual Meeting.....	Dec. 1952 64
55	Caraso, I. R., T. M. Morong and E. J. Lauerman—Kyrene Steam Plant Designed for Southwest Conditions.....	Oct. 1952 48
64	Cardwell, P. H.—Chemical Cleaning in Central Stations, ASME Spring Meeting.....	May 1953 55
43	Cary, S. B., I. W. Gross and C. F. Wagner—Progress and Future Trends in Electric Transmission, Century of Engineering.....	Oct. 1952 42
57	Castellani, Dr. Claudio—New Italian Power Station Operates at 1850 Psig.....	July 1952 32
58	Castelli, Dott. Ing. Franco—Piacenza Station of the Societa Edison.....	Sept. 1952 36
59	Cheney, F. C., and T. A. Fearnside—Industrial Power Plant Construction Costs.....	Jan. 1953 47
	Cisler, Walker L., Louis C. McCabe, W. L. Davidson, Walter H. Zinn and O. M. Ruebhausen—Nuclear Power Symposium, American Power Conference.....	Apr. 1953 55
59	Clark, Philip M., and J. F. Cage, Jr.—Pumps for Handling Liquid Metals, ASME Annual Meeting.....	Dec. 1952 58
	Colan, Leo J.—Operating Spreader Stokers.....	Oct. 1952 64

		PAGE
	Coldwell, F. H.—Power Expansion at Nekoosa-Edwards Paper Co.....	Feb. 1953 49
	Condict, E. C.—The Minimum Continuous Safe Flow of Centrifugal Pumps.....	Aug. 1952 55
	Corey, R. C., and James W. Myers—Furnace-Heat Absorption Efficiency as Shown by Enthalpy of Gases Leaving the Furnace, ASME Annual Meeting.....	Dec. 1952 56
	Utilization of Low-Grade Coals for Power Generation.....	Sept. 1952 43
	Crossley, H. E.—External Boiler Tube Deposits.....	Oct. 1952 61
	Davidson, W. L., Louis C. McCabe, Walter H. Zinn, Walker L. Cisler and O. M. Ruebhausen—Nuclear Power Symposium, American Power Conference.....	Apr. 1953 55
	de Lorenzi, Otto—Influence of Low-Quality Coal on Pulverized-Fuel-Fired Units.....	Nov. 1952 46
	3,000,000 Kw Operating Experience with Modern Reheat.....	May 1953 47
	Turbulent Suspension Burning.....	Feb. 1953 55
	de Luccia, E. Robert—Are Federal Power Practices Sound National Policy?, American Power Conference.....	Apr. 1953 54
	Dickey, P. S.—Trends in Combustion and Steam Temperature Control, American Power Conference.....	Apr. 1953 51
	Dolezal, Dr. Richard—Improved Utilization of Waste Heat.....	Sept. 1952 57
	Douglass, D., A. M. Hall and J. H. Jackson—Corrosion of Mercury Boiler Tubes During Combustion of a Heavy Residual Oil, ASME Annual Meeting.....	Dec. 1952 62
	Drake, W. V., and R. A. Mycoff—Milesburg Power Station, ASME Semi-Annual Meeting.....	July 1952 39
	Drapier, Philip—Residual Fuel Oils in Gas Turbines, ASME Annual Meeting.....	Dec. 1952 62
	Elston, C. W.—Quick Starting of Turbines, ASME Annual Meeting.....	Dec. 1952 54
	Erythropel, H.—New Steam Table Up to 700 C.....	Mar. 1953 55
	Exley, L. M.—Experience with Furnace Television.....	Nov. 1952 63
	Falkner, J. C.—Quick Starting of Large High-Pressure, High-Temperature Boilers, ASME Annual Meeting.....	Dec. 1952 53
	Fearnside, T. A., and F. C. Cheney—Industrial Power Plant Construction Costs.....	Jan. 1953 47
	Feeley, F. G., Jr.—Industrial Power Construction Costs, ASME Annual Meeting.....	Dec. 1952 56
	Feeley, F. G., Jr., and Earle C. Miller—Variation in Furnace Heat-Absorption as Shown by Measurement of Temperature of Exposed Side of Furnace Tubes, ASME Annual Meeting.....	Dec. 1952 57
	Feeney, V. J.—Greenwich Steam Generating Station of Atlantic City Electric Co.....	Apr. 1953 40
	Fong, James T.—Optimum Design for Surface Condensers, ASME Fall Meeting.....	Oct. 1952 46
	Forgeur, Baron A.—The Fernand Courtot Power Station at Awirs, Liege.....	Aug. 1952 40
	Funk, Max O.—Relation of Spreader Stokers to Air Pollution.....	July 1952 41
	Gardiner, C. M., B. O. Buckland and D. G. Sanders—Residual Fuel Oil Ash Corrosion, ASME Annual Meeting.....	Dec. 1952 61
	Geue, John E., F. E. Nicoson, J. D. Williamson, Albert H. Beiler, D. F. Steinke and Vern L. Stone—Training Power Plant Personnel, A Symposium, ASME Semi-Annual Meeting.....	July 1952 37
	Gow, J. T., J. H. Jackson, C. J. Slunder and O. H. Harder—Resistance of Cast Fe-Cr-Ni Alloys to Corrosion in Oxidizing and Reducing Flue-Gas Atmospheres, ASME Annual Meeting.....	Dec. 1952 61
	Gowdy, G. H., and S. B. Applebaum—Conversion of a Two-Stage Hot Process Water Softener from Hot Lime-Soda Phosphate to Hot Lime Zeolite at Cambridge Electric Light Co., ASME Annual Meeting.....	Dec. 1952 63
	Gran, Sal—Industrial Power Plant Operation (Penal Institution), American Power Conference.....	Apr. 1953 52
	Greacen, Walter III—Breaker Bars for Traveling Grate Stokers.....	Nov. 1952 43
	Gross, I. W., S. B. Cary and C. F. Wagner—Progress and Future Trends of Electric Transmission, Century of Engineering.....	Oct. 1952 42
	Guillory, H. J.—Experience with Amines, American Power Conference.....	Apr. 1953 53
	Hahn, Gordon R.—Instrumentation for Detection of Stack Emissions.....	Dec. 1952 67
	Halitsky, James, and Gordon H. Strom—Topographical Influences on Dispersal of Stack Gases.....	June 1953 40
	Hall, A. M., D. Douglass and J. H. Jackson—Corrosion of Mercury Boiler Tubes During Combustion of a Heavy Residual Oil, ASME Annual Meeting.....	Dec. 1952 62
	Hall, A. M., C. J. Slunder and J. H. Jackson—Superheater Tubing Materials for High Temperatures, ASME Annual Meeting.....	Dec. 1952 60
	Hall, Walter H.—Power and Steam Generation at Chillothe Division of The Mead Corporation.....	Jan. 1953 36
	Hammond, William, and Hilmer Karlsson—Air Preheater Design as Affected by Fuel Characteristics, ASME Annual Meeting.....	Dec. 1952 59
	Harder, O. H., J. H. Jackson, C. J. Slunder and J. T. Gow—Resistance of Cast Fe-Cr-Ni Alloys to Corrosion in Oxidizing and Reducing Flue-Gas Atmospheres, ASME Annual Meeting.....	Dec. 1952 61
	Hazard, Herbert R.—Some Practical Aspects of Combustion in the Gas Turbine, American Power Conference.....	Apr. 1953 56
	Hewson, E. Wendell, Dr. Robert A. Kehoe, P. W. Zimmerman, George F. Jenkins and Leslie Silverman—Air Pollution Symposium, ASME Annual Meeting.....	Dec. 1952 65

	PAGE		PAGE
Hiebeler, H. G.— <i>South Texas Outdoor Power Stations, ASME Fall Meeting.</i>	Oct. 1952 44	Conference	Apr. 1953 54
Hill, J. S., R. S. Wise, George Illig, J. F. Wilkes and J. K. Rice— <i>Cooling Towers, Panel Discussion, Thirteenth Annual Water Conference.</i>	Nov. 1952 55	Morong, T. M., I. R. Caraco and E. J. Lauerman— <i>Kyrene Steam Plant Designed for Southwest Conditions.</i>	Oct. 1952 48
Holler, E. J., Jr., and J. B. McIlroy— <i>Additives to Fuel Oil, Part I, ASME Annual Meeting.</i>	Dec. 1952 62	Morris, E. B., and C. E. Brune— <i>Economics, the Key to Evaporation Vs. Demineralization for Makeup in High-Pressure Steam Power Plants, American Power Conference.</i>	Apr. 1953 53
Hoppe, T. C., and R. A. Russell— <i>Deionization Vs. Evaporation of Hard Water Supplies for Boiler Makeup, Thirteenth Annual Water Conference.</i>	Nov. 1952 54	Mosshart, D. J.— <i>Present-Day Thoughts on the Application of Single-Retort Underfeed Stokers, ASME Annual Meeting.</i>	Dec. 1952 58
Hormell, D. C.— <i>Design for Extreme Flood Conditions at the Paddy's Run Station, ASME Semi-Annual Meeting.</i>	July 1952 37	Mumford, A. R.— <i>District Heating, Century of Engineering.</i>	Oct. 1952 41
Illig, George, J. S. Hill, J. F. Wilkes, R. S. Wise and J. K. Rice— <i>Cooling Towers, Panel Discussion, Thirteenth Annual Water Conference.</i>	Nov. 1952 55	Mycoff, R. A., and W. V. Drake— <i>Milesburg Power Station, ASME Semi-Annual Meeting.</i>	July 1952 39
Impagliazzo, A. M.— <i>Feedwater Conditioning by Evaporation, American Power Conference.</i>	Apr. 1953 52	Myers, James W., and R. C. Corey— <i>Furnace-Heat Absorption Efficiency as Shown by Enthalpy of Gases Leaving the Furnace, ASME Annual Meeting.</i>	Dec. 1952 56
Irwin, K. M.— <i>Engineering Economy in the Electric Utility Industry.</i>	Sept. 1952 53	Utilization of Low-Grade Coals for Power Generation	Sept. 1952 43
Jackson, J. H., A. M. Hall and D. Douglass— <i>Corrosion of Mercury Boiler Tubes During Combustion of a Heavy Residual Oil, ASME Annual Meeting.</i>	Dec. 1952 62	Nelson, D. B., and Thomas Trocki— <i>Liquid Metal as a Heat Transfer Medium, ASME Annual Meeting.</i>	Dec. 1952 57
Jackson, J. H., C. J. Slunder, O. H. Harder and J. T. Gow— <i>Resistance of Cast Fe-Cr-Ni Alloys to Corrosion in Oxidizing and Reducing Flue-Gas Atmospheres, ASME Annual Meeting.</i>	Dec. 1952 61	Nicoson, F. E., J. D. Williamson, Albert H. Beiler, John E. Geue, D. F. Steinke and Vern L. Stone— <i>Training Power Plant Personnel, A Symposium, ASME Semi-Annual Meeting.</i>	July 1952 37
Jackson, J. H., C. J. Slunder and A. M. Hall— <i>Superheater Tubing Materials for High Temperatures, ASME Annual Meeting.</i>	Dec. 1952 60	Novak, R. E.— <i>Preparing Steam Generating Unit for Service at O. H. Hutchings Station.</i>	June 1953 45
Jenkins, George F., Dr. Robert A. Kehoe, P. M. Zimmerman, E. Wendell Hewson and Leslie Silverman— <i>Air Pollution Symposium, ASME Annual Meeting.</i>	Dec. 1952 65	Ongman, Harry D.— <i>A Study of Reducing Solutions at Steam Boiler Temperatures.</i>	Feb. 1953 40
Jenkins, T. W., Jr.— <i>Superheater Tube Measurements.</i>	Apr. 1953 59	Parkinson, R. W., Arthur Larnard, Herman Weisberg, E. H. Krieg and H. A. Wagner— <i>Central Station Construction Costs, Panel Discussion, ASME Annual Meeting.</i>	Dec. 1952 55
Johnson, A. A., and A. C. Monteith— <i>Past Progress and Present Trends in the Art of Power Generation, Century of Engineering.</i>	Oct. 1952 41	Parmakian, G., and E. F. Rothemich— <i>Tabular Air Heater Problems, ASME Annual Meeting.</i>	Dec. 1952 60
Joslin, L. E.— <i>Industrial Power Plant Operation (Packing House), American Power Conference.</i>	Apr. 1953 52	Payne, Warren, and J. J. McMullen— <i>Performance of Free-Piston Gas Generators, ASME Spring Meeting.</i>	May 1953 54
Judson, C. J., R. B. Boals and Dale Bumstead, Jr.— <i>Wood Burning in a Central Station (City of Eugene, Ore.), ASME Annual Meeting.</i>	Dec. 1952 59	Porterfield, C. W., and E. J. Boer— <i>Dust Emissions from Small Spreader-Stoker-Fired Boilers, ASME Spring Meeting.</i>	May 1953 58
Juhász, Stephen— <i>Sulfur Trioxide in Flue Gases.</i>	June 1953 53	Powell, E. B., and J. D. Ristroph— <i>Condensate Contamination, ASME Annual Meeting.</i>	Dec. 1952 63
Karlsson, Hilmner, and William Hammond— <i>Air Preheater Design as Affected by Fuel Characteristics, ASME Annual Meeting.</i>	Dec. 1952 59	Ptacek, Frank— <i>Development of Improvements in Boiler Water Level Gages.</i>	Oct. 1952 56
Kehoe, Dr. Robert A., P. W. Zimmerman, E. Wendell Hewson, George F. Jenkins and Leslie Silverman— <i>Air Pollution Symposium, ASME Annual Meeting.</i>	Dec. 1952 65	Purell, D. N., and V. B. Burgess— <i>Demineralizing Experience, ASME Fall Meeting.</i>	Oct. 1952 46
Keinath, Gerald E., Ralph A. Sherman and R. Tom Sawyer— <i>The Combustion of Pulverized Coal in a Water-Cooled Radiant Tube, ASME Annual Meeting.</i>	Dec. 1952 65	Pursell, J. W., Jr., F. L. Archibald and F. G. Straub— <i>Prevention of Metal Losses in the Wet Steam Areas of Steam Turbines, American Power Conference.</i>	Apr. 1953 51
Kennison, R. A.— <i>Vorticity Heat Transfer in Molten Metals, ASME Annual Meeting.</i>	Dec. 1952 58	Quill, J. S., and T. R. Rhea— <i>Gas Turbines and Centrifugal Compressors for Natural Gas Pipelines, ASME Annual Meeting.</i>	Dec. 1952 64
Kilbourne, C. E., Carl Schabtach and J. B. McClure— <i>Design and Application of Large Steam Turbines, American Power Conference.</i>	Apr. 1953 48	Ramsey, Robert P., and J. J. McMullen— <i>The Free-Piston Type of Gas-Turbine Plant and Applications, ASME Spring Meeting.</i>	May 1953 53
Krieg, E. H., Arthur Larnard, Herman Weisberg, H. A. Wagner and R. W. Parkinson— <i>Central Station Construction Costs, Panel Discussion, ASME Annual Meeting.</i>	Dec. 1952 55	Reese, Homer R.— <i>Development of the 3600-rpm Turbine, American Power Conference.</i>	Apr. 1953 48
Lasley, Robert A., and Frank M. Lewis— <i>The Development of High-Output Free-Piston Gas Generators, ASME Spring Meeting.</i>	May 1953 54	Rhea, T. R., and J. S. Quill— <i>Gas Turbines and Centrifugal Compressors for Natural Gas Pipelines, ASME Annual Meeting.</i>	Dec. 1952 64
Larnard, Arthur, Herman Weisberg, E. H. Krieg, H. A. Wagner and R. W. Parkinson— <i>Central Station Construction Costs, Panel Discussion, ASME Annual Meeting.</i>	Dec. 1952 55	Rice, J. K., J. S. Hill, R. S. Wise, George Illig and J. F. Wilkes— <i>Cooling Towers, Panel Discussion, Thirteenth Annual Water Conference.</i>	Nov. 1952 56
Lauerman, E. J., T. M. Morong and I. R. Caraco— <i>Kyrene Steam Plant Designed for Southwest Conditions.</i>	Oct. 1952 48	Rich, Arnold— <i>A Classification of Outages of Facilities in Electric Power Systems.</i>	Mar. 1953 43
Lee, R.— <i>Additives to Fuel Oil, Part II, ASME Annual Meeting.</i>	Dec. 1952 62	Ringland, W. L., and L. T. Rosenberg— <i>Present Status of Supercharged Cooling, American Power Conference.</i>	Apr. 1953 49
Lewis, Frank M., and Robert A. Lasley— <i>The Development of High-Output Free-Piston Gas Generators, ASME Spring Meeting.</i>	May 1953 43	Ristroph, J. D., and E. B. Powell— <i>Condensate Contamination, ASME Annual Meeting.</i>	Dec. 1952 63
Lindsay, F. K.— <i>Acid Regeneration of Cation Exchangers, American Power Conference.</i>	Apr. 1953 53	Rogers, W. C.— <i>Mill Drying in Pulverizing High-Moisture Coals, ASME Spring Meeting.</i>	May 1953 57
Liversidge, R. P.— <i>Experience with Large Generating Units, American Power Conference.</i>	Apr. 1953 47	Robinson, C. S.— <i>Economical Industrial Power Plant Design, ASME Annual Meeting.</i>	Dec. 1952 55
McCabe, Louis C., W. L. Davidson, Walter H. Zinn, Walker L. Cislér and O. M. Ruebhausen— <i>Nuclear Power Symposium, American Power Conference.</i>	Apr. 1953 55	Robinson, Richard L.— <i>Some Theoretical Aspects of Centripetal Turbines, ASME Spring Meeting.</i>	May 1953 55
McClure, J. B., Carl Schabtach and C. E. Kilbourne— <i>Design and Application of Large Steam Turbines, American Power Conference.</i>	Apr. 1953 48	Rohrig, I. A., and H. S. Blumberg— <i>Local Carbide Segregation and Decarburization in Welded Joints.</i>	Mar. 1953 36
McIlroy, J. B., and E. J. Holler, Jr.— <i>Additives to Fuel Oil, Part I, ASME Annual Meeting.</i>	Dec. 1952 62	Rosenberg, L. T., and W. L. Ringland— <i>Present Status of Supercharged Cooling, American Power Conference.</i>	Apr. 1953 49
McMullen, J. J., and Warren Payne— <i>Performance of Free-Piston Gas Generators, ASME Spring Meeting.</i>	May 1953 54	Rosenblatt, A. L., and R. D. Brooks— <i>Design and Performance of Liquid-Metal Heat-Exchangers and Steam Generators for Nuclear Power Plants, ASME Annual Meeting.</i>	Dec. 1952 58
Maguire, John J., and R. E. Winston— <i>Effect of Operating Pressure on Carbon Dioxide Content of Steam, Thirteenth Annual Water Conference.</i>	Nov. 1952 56	Rothemich, E. F., and G. Parmakian— <i>Tabular Air Heater Problems, ASME Annual Meeting.</i>	Dec. 1952 60
Miller, E. C., and F. G. Feeley, Jr.— <i>Variation in Furnace Heat-Absorption as Shown by Measurement of Temperature of Exposed Side of Furnace Tubes, ASME Annual Meeting.</i>	Dec. 1952 57	Ruebhausen, O. M., Louis C. McCabe, W. L. Davidson, Walter H. Zinn and Walker L. Cislér— <i>Nuclear Energy Symposium, American Power Conference.</i>	Apr. 1953 56
Monteith, A. C., and A. A. Johnson— <i>Past Progress and Present Trends in the Art of Power Generation, Century of Engineering.</i>	Oct. 1952 41	Russell, R. A., and T. C. Hoppe— <i>Deionization Vs. Evaporation of Hard Water Supplies for Boiler Makeup, Thirteenth Annual Water Conference.</i>	Nov. 1952 54
Moore, J. F.— <i>The Materials Situation, American Power</i>		Sage, A. M.— <i>Creep in Steels for Steam Power Plants.</i>	Apr. 1953 63
		Sanders, D. G., B. O. Buckland and C. M. Gardiner— <i>Residual Fuel Oil Ash Corrosion, ASME Annual Meeting.</i>	Dec. 1952 61
		Sawyer, R. Tom, Ralph A. Sherman and Gerald E. Keinath— <i>The Combustion of Pulverized Coal in a Water-Cooled Radiant Tube, ASME Annual Meeting.</i>	Dec. 1952 65
		Schabtach, C., C. E. Kilbourne and J. B. McClure—	

AGE
54
48
53
58
41
39
56
43
57
37
45
40
55
60
54
58
63
56
46
51
64
53
48
64
56
43
49
63
57
55
36
49
58
60
61
65
ON

	PAGE
<i>Design and Application of Large Steam Turbines, American Power Conference.</i> Apr. 1953	48
Schierland, Raymond F.— <i>Handling Material for the Walter C. Beckjord Station.</i> Aug. 1952	51
Schreitz, W. G., and W. C. Stewart— <i>Thermal Shock and Other Comparison Tests of Austenitic and Ferritic Steels for Main Steam Piping, ASME Annual Meeting.</i> Dec. 1952	63
Seybolt, Alan U.— <i>Metals and Metal Processing in the Atomic Energy Field.</i> July 1952	47
Sherman, Ralph A., Gerald E. Keinath and R. Tom Sawyer— <i>The Combustion of Pulverized Coal in a Water-Cooled Radiant Tube, ASME Annual Meeting.</i> Dec. 1952	65
Sibbitt, W. L., L. M. Zoss and S. Suciu— <i>The Solubility of Oxygen in Water, ASME Spring Meeting.</i> May 1953	56
Silverman, Leslie, Dr. Robert A. Kehoe, P. W. Zimmerman, E. Wendell Hewson and George F. Jenkins— <i>Air Pollution Symposium, ASME Annual Meeting.</i> Dec. 1952	65
Slunder, C. J., J. H. Jackson, O. H. Harder and J. T. Gow— <i>Resistance of Cast Fe-Cr-Ni Alloys to Corrosion in Oxidizing and Reducing Flue-Gas Atmospheres, ASME Annual Meeting.</i> Dec. 1952	61
Slunder, C. J., A. M. Hall and J. H. Jackson— <i>Superheater Tubing Materials for High Temperatures, ASME Annual Meeting.</i> Dec. 1952	60
Steinke, D. F., F. E. Nicoson, J. D. Williamson, Albert H. Beiler, John E. Geue and Vern L. Stone— <i>Training Power Plant Personnel, A Symposium, ASME Semi-Annual Meeting.</i> July 1952	37
Stenard, R. K., and V. J. Calise— <i>Experiences with Application of Deaerating Heaters in Feedwater Cycles, Thirteenth Annual Water Conference.</i> Nov. 1952	54
Stewart, W. C., and W. G. Schreitz— <i>Thermal Shock and Other Comparison Tests of Austenitic and Ferritic Steels for Main Steam Piping, ASME Annual Meeting.</i> Dec. 1952	63
Stone, Vern L., F. E. Nicoson, J. D. Williamson, Albert H. Beiler, John E. Geue and D. F. Steinke— <i>Training Power Plant Personnel, A Symposium, ASME Semi-Annual Meeting.</i> July 1952	37
Stone, William J.— <i>Application of Metallic Phosphates to Cooling Water Treatment, Thirteenth Annual Water Conference.</i> Nov. 1952	55
Strange, John P.— <i>The Smokescope—An Instrument for Estimating the Density of Smoke in Stack Effluent, ASME Spring Meeting.</i> May 1953	58
Straub, F. G., F. L. Archibald and J. W. Purssell, Jr.— <i>Prevention of Metal Losses in the Wet Steam Areas of Steam Turbines, American Power Conference.</i> Apr. 1953	51
Strom, Gordon H., and James Halitsky— <i>Topographical Influences on Dispersal of Stack Gases.</i> June 1953	40
Suciu, S., L. M. Zoss and W. L. Sibbitt— <i>The Solubility of Oxygen in Water, ASME Spring Meeting.</i> May 1953	56
Tammaro, Alfonso— <i>Industrial Applications of Nuclear Energy, ASME Fall Meeting.</i> Oct. 1952	47
Travis, Richard J., and James W. Campbell— <i>Overfire Air Installation at the Conners Creek Power Plant, ASME Spring Meeting.</i> May 1953	56
Trocki, Thomas, and D. B. Nelson— <i>Liquid Metal as a Heat Transfer Medium, ASME Annual Meeting.</i> Dec. 1952	57
Wagner, C. F., S. B. Cary and I. W. Gross— <i>Progress and Future Trends in Electric Transmission, Century of Engineering.</i> Oct. 1952	42
Wagner, H. A., Arthur Larnard, Herman Weisberg, E. H. Krieg and R. W. Parkinson— <i>Central Station Construction Costs, Panel Discussion, ASME Annual Meeting.</i> Dec. 1952	55
Webb, E. C., and J. E. Atchinson— <i>Applications and Performance of Single-Retort Underfeed Stokers, ASME Annual Meeting.</i> Dec. 1952	58
Weiner, S., and E. Aslaksen— <i>Dechy Power Plant at Sin-Le-Noble, Nord France.</i> Dec. 1952	38
Weisberg, Herman— <i>Boiler Construction Costs.</i> Feb. 1953	45
Wenzel, A. C.— <i>Boiler Controls for Multiple Fuels, ASME Fall Meeting.</i> Oct. 1952	43
Wheelock, B. R., Jr.— <i>Reading Modernizes Its Power Plant.</i> Nov. 1952	38
White, H. J.— <i>Electrostatic Precipitators.</i> Mar. 1953	49
Widsteen, P. E.— <i>Steam Plant Cuts Unit Cost Over Diesel Operation at Menasha.</i> June 1953	57
Wilkes, J. F., J. S. Hill, George Illig, R. S. Wise and J. K. Rice— <i>Cooling Towers, Panel Discussion, Thirteenth Annual Water Conference.</i> Nov. 1952	55
Williamson, G. V.— <i>New Features of Steam Plants on Inland Rivers, ASME Semi-Annual Meeting.</i> July 1952	39
Williamson, J. D., F. E. Nicoson, Albert H. Beiler, John E. Geue, D. F. Steinke and Vern L. Stone— <i>Training Power Plant Personnel, A Symposium, ASME Semi-Annual Meeting.</i> July 1952	37
Wilson, Charles D.— <i>Cross-Compound Designs, American Power Conference.</i> Apr. 1953	49
Winston, R. E., and J. J. Maguire— <i>Effect of Operating Pressure on Carbon Dioxide Content of Steam, Thirteenth Annual Water Conference.</i> Nov. 1952	56
Wise, R. S., J. S. Hill, George Illig, J. F. Wilkes and J. K. Rice— <i>Cooling Towers, Panel Discussion, Thirteenth Annual Water Conference.</i> Nov. 1952	55
Worley, Robert W., and Harold J. Bentson— <i>Steel Works Power Plants, ASME Fall Meeting.</i> Oct. 1952	44
Yonick, W. M., and G. W. Bice— <i>Pressure Operation, ASME Fall Meeting.</i> Oct. 1952	45
Zimmerman, P. W., Dr. Robert A. Kehoe, E. Wendell Hewson, George F. Jenkins and Leslie Silverman—	

<i>Air Pollution Symposium, ASME Annual Meeting.</i> Dec. 1952	65
Zinn, Walter H.— <i>Engineering and Technical Problems of Atomic Power.</i> June 1953	49
Zoss, L. M., S. Suciu and W. L. Sibbitt— <i>The Solubility of Oxygen in Water, ASME Spring Meeting.</i> May 1953	56

CLASSIFIED

Acid Cleaning

<i>Chemical Cleaning in Central Stations, ASME Spring Meeting.</i> By P. H. Cardwell May 1953	55
<i>Preparing Steam Generating Unit for Service at O. H. Hutchings Station.</i> By R. E. Novak June 1953	45

Air Heaters

<i>Air Preheater Design as Affected by Fuel Characteristics, ASME Annual Meeting.</i> By Hilmer Karlsson and William Hammond Dec. 1952	59
<i>Preheating Combustion Air by Extracted Steam.</i> By S. Bente Jan. 1953	57
<i>Tubular Air Heater Problems, ASME Annual Meeting.</i> By E. F. Rothemich and G. Parmakian Dec. 1952	60

Atmospheric Pollution

<i>Air Pollution Symposium, ASME Annual Meeting: Dr. Robert A. Kehoe, P. W. Zimmerman, E. Wendell Hewson, George F. Jenkins and Leslie Silverman.</i> Dec. 1952	65
<i>Dust Emissions from Small Spreader-Stoker-Fired Boilers, ASME Spring Meeting.</i> By E. J. Boer and C. W. Porterfield May 1953	58
<i>Electrostatic Precipitators.</i> By H. J. White Mar. 1953	49
<i>Instrumentation for Detection of Stack Emissions.</i> By Gordon R. Hahn Dec. 1952	67
<i>Meteorological Aspects of Air Pollution Control.</i> By O. K. Anderson Jan. 1953	52
<i>Relation of Spreader Stokers to Air Pollution.</i> By Max O. Funk July 1952	41
<i>Series Dust-Collector Installations on Large Pulverized Coal Boilers.</i> By L. W. Cadwallader Aug. 1952	47
<i>Smokescope, The—An Instrument for Estimating the Density of Smoke in Stack Effluent, ASME Spring Meeting.</i> By John P. Strange May 1953	58
<i>Topographical Influences in Dispersal of Stack Gases.</i> By Gordon H. Strom and James Halitsky June 1953	40

Boilers

<i>Boiler Construction Costs.</i> By Herman Weisberg Feb. 1953	45
<i>Development of Improvements in Boiler Water Level Gages.</i> Oct. 1952	56
<i>External Boiler Tube Deposits.</i> By H. E. Crossley Oct. 1952	61
<i>Sulfur Trioxide in Flue Gases.</i> By Stephen Juhasz June 1953	53
<i>Units for Joppa.</i> Oct. 1952	55

Condensers

<i>Optimum Design for Surface Condensers, ASME Fall Meeting.</i> By James T. Fong Oct. 1952	46
---	----

Controls

<i>Boiler Controls for Multiple Fuels, ASME Fall Meeting.</i> By A. C. Wenzel Oct. 1952	43
<i>Trends in Combustion and Steam Temperature Control, American Power Conference.</i> By P. S. Dickey Apr. 1953	51

Corrosion

<i>Corrosion of Mercury Boiler Tubes During Combustion of a Heavy Residual Oil, ASME Annual Meeting.</i> By A. M. Hall, D. Douglass and J. H. Jackson Dec. 1952	62
<i>Residual Fuel Oil Ash Corrosion, ASME Annual Meeting.</i> By B. O. Buckland, C. M. Gardiner and D. G. Sanders Dec. 1952	61
<i>Resistance of Cast Fe-Cr-Ni Alloys to Corrosion in Oxidizing and Reducing Flue-Gas Atmospheres, ASME Annual Meeting.</i> By J. H. Jackson, C. J. Slunder, O. H. Harder and J. T. Gow Dec. 1952	61
<i>Sulfur Trioxide in Flue Gases.</i> By Stephen Juhasz June 1953	53

Costs

<i>Boiler Construction Costs.</i> By Herman Weisberg Feb. 1953	45
<i>Central Station Construction Costs, Panel Discussion, ASME Annual Meeting: Arthur Larnard, Herman Weisberg, E. H. Krieg, H. A. Wagner and R. W. Parkinson.</i> Dec. 1952	55
<i>Industrial Power Construction Costs, ASME Annual Meeting.</i> By F. G. Feeley, Jr. Dec. 1952	56
<i>Industrial Power Plant Construction Costs.</i> By T. A. Fearnside and F. C. Cheney Jan. 1953	47
<i>Investment Costs—Industrial Power Plants, ASME Annual Meeting.</i> By John Campbell Dec. 1952	56

	PAGE		PAGE
Demineralization		Kyrene Steam Plant, Salt River Power District. <i>Kyrene Steam Plant Designed for Southwest Conditions.</i> By T. M. Morong, I. R. Caraco and E. J. Lauerman.	
Demineralizing Experience, <i>ASME Fall Meeting.</i> By V. B. Burgess and D. N. Purcell.	Oct. 1952 46	Milesburg Power Station, West Penn Power Company. <i>Milesburg Power Station, ASME Semi-Annual Meeting.</i> By W. V. Drake and R. A. Mycoff.	July 1952 39
Economics, the Key to Evaporation Vs. Demineralization for Makeup in High-Pressure Steam Power Plants, <i>American Power Conference.</i> By E. B. Morris and C. E. Brune.	Apr. 1953 53	Nekoosa-Edwards Paper Co. <i>Power Expansion at Nekoosa-Edwards Paper Co.</i> By Frank H. Coldwell.	Feb. 1953 49
Design		Piacenza Station, Societa Edison. <i>Piacenza Station of the Societa Edison.</i> By Dott. Ing. Franco Castelli.	Sept. 1952 36
Economical Industrial Power Plant Design, <i>ASME Annual Meeting.</i> By C. S. Robinson.	Dec. 1952 55	Reading Company, Reading, Pennsylvania. <i>Reading Modernizes Its Power Plant.</i> By B. R. Wheelock, Jr.	Nov. 1952 38
Engineering Economy in the Electric Utility Industry. By K. M. Irwin.	Sept. 1952 53	Tavazzano Station, Societa Termo Elettrica Italiana (STEI). <i>New Italian Power Station Operates at 1850 Psig.</i> By Dr. Claudio Castellani.	July 1952 32
Fuels		Villanova College, Villanova, Pennsylvania. <i>Modern Steam Plant at Villanova College.</i>	Sept. 1952 50
Combustion of Pulverized Coal in a Water-Cooled Radiant Tube, <i>ASME Annual Meeting.</i> By Ralph A. Sherman, Gerald E. Keinath and R. Tom Sawyer.	Dec. 1952 65	Instruments	
Influence of Low-Quality Coal on Pulverized-Fuel-Fired Units. By Otto de Lorenzi.	Nov. 1952 46	Development of Improvements in Boiler Water Level Gages. By Frank Ptacek.	Oct. 1952 56
Process for Utilizing Western Lignite.	May 1953 61	Lubrication	
Wood Burning in a Central Station (City of Eugene, Ore.), <i>ASME Annual Meeting.</i> By R. B. Boals, Dale Bumstead, Jr., and C. J. Judson.	Dec. 1952 59	Effects of Temperature on Steam Turbine Oil. By Thomas L. Byrne.	May 1953 45
Furnaces		Materials	
Experience with Furnace Television. By L. M. Exley.	Nov. 1952 63	Creep in Steels for Steam Power Plants. By A. M. Sage.	Apr. 1953 63
Pressure Operation, <i>ASME Fall Meeting.</i> By G. W. Bice and W. M. Yeknik.	Oct. 1952 45	Materials Situation, The, <i>American Power Conference.</i> By J. F. Moore.	Apr. 1953 54
Gas Turbines		Nuclear Energy	
Development of High-Output Free-Piston Gas Generators, <i>ASME Spring Meeting.</i> By Frank M. Lewis and Robert A. Lasley.	May 1953 54	Design and Performance of Liquid-Metal Heat-Exchangers and Steam Generators for Nuclear Power Plants, <i>ASME Annual Meeting.</i> By R. D. Brooks and A. L. Rosenblatt.	Dec. 1952 58
Free-Piston Type of Gas-Turbine Plant and Applications, The, <i>ASME Spring Meeting.</i> By J. J. McMullen and Robert P. Ramsey.	May 1953 53	Engineering and Technical Problems of Atomic Power. By Walter H. Zinn.	June 1953 49
Gas Turbines and Centrifugal Compressors for Natural Gas Pipelines, <i>ASME Annual Meeting.</i> By T. R. Rhea and J. S. Quill.	Dec. 1952 64	Expert Sees Economic Atomic Power 10 to 15 Years Off.	May 1953 60
Performance of Free-Piston Gas Generators, <i>ASME Spring Meeting.</i> By J. J. McMullen and Warren Payne.	May 1953 54	Industrial Applications of Nuclear Energy, <i>ASME Fall Meeting.</i> By Alfonso Tammaro.	Oct. 1952 47
Some Practical Aspects of Combustion in the Gas Turbine, <i>American Power Conference.</i> By Herbert R. Hazard.	Apr. 1953 56	Liquid Metal as a Heat Transfer Medium, <i>ASME Annual Meeting.</i> By Thomas Trocki and D. B. Nelson.	Dec. 1952 57
Industrial Power		Metals and Metal Processing in the Atomic Energy Field. By Alan U. Seybolt.	July 1952 47
Economical Industrial Power Plant Design, <i>ASME Annual Meeting.</i> By C. S. Robinson.	Dec. 1952 55	Nuclear Power Symposium, <i>American Power Conference.</i> Louis C. McCabe, W. L. Davidson, Walter H. Zinn, Walker L. Cislir and O. M. Ruebhausen.	Apr. 1953 55
Industrial Power Construction Costs, <i>ASME Annual Meeting.</i> By F. G. Feeley, Jr.	Dec. 1952 56	Oil Firing	
Industrial Power Plant Construction Costs. By T. A. Fearnside and F. C. Cheney.	Jan. 1953 47	Additives to Fuel Oil, Part I, <i>ASME Annual Meeting.</i> By J. B. McIlroy and E. J. Holler, Jr.	Dec. 1952 62
Industrial Power Plant Operation, <i>American Power Conference.</i> Wyle Austin (Paper Mill), L. E. Joslin (Packing House), C. R. Bender (Hospital), Sal Gran (Penal Institution).	Apr. 1953 52	Additives to Fuel Oil, Part II, <i>ASME Annual Meeting.</i> By R. Lee.	Dec. 1952 62
Investment Costs—Industrial Power Plants, <i>ASME Annual Meeting.</i> By John Campbell.	Dec. 1952 56	Residual Fuel Oil Ash Corrosion, <i>ASME Annual Meeting.</i> By B. O. Buckland, C. M. Gardiner and D. G. Sanders.	Dec. 1952 61
Steel Works Power Plants, <i>ASME Fall Meeting.</i> By Robert W. Worley and Harold J. Bentson.	Oct. 1952 44	Use of Residual Fuel Oils in Gas Turbines, <i>ASME Annual Meeting.</i> By Philip Draper.	Dec. 1952 62
Heaters		Operation	
Experiences with Application of Deaerating Heaters in Feedwater Cycles, <i>Thirteenth Annual Water Conference.</i> By V. J. Calise and R. K. Stenard.	Nov. 1952 54	Preparing Steam Generating Unit for Service at O. H. Hutchings Station. By R. E. Novak.	June 1953 45
Installations		Steam Plant Cuts Unit Cost over Diesel Operation at Menasha. By P. E. Widsteen.	June 1953 59
Beckjord Station, Walter C., Cincinnati Gas & Electric Company. <i>Handling Material for the Walter C. Beckjord Station.</i> By Raymond F. Schierland.	Aug. 1952 51	Outdoor Power Plants	
Bokaro Steam Power Plant, Damodar Valley Corporation. <i>Bokaro Placed in Service.</i>	Mar. 1953 64	South Texas Outdoor Power Stations, <i>ASME Fall Meeting.</i> By Harry G. Hiebeler.	Oct. 1952 44
Chillicothe Division, The Mead Corporation. <i>Power and Steam Generation at Chillicothe Division of The Mead Corporation.</i> By Walter H. Hall.	Jan. 1953 36	Piping	
Courtroy Power Station, Fernand, Awirs, Leige. <i>The Fernand Courtroy Power Station at Awirs, Leige.</i> By Baron A. Forgeur.	Aug. 1952 40	Local Carbide Segregation and Decarburization in Welded Joints. By H. S. Blumberg and I. A. Rohrig.	Mar. 1953 36
Dechy Power Plant, Houilleres du Bassin du Nord et du Pas-de-Calais. <i>Dechy Power Plant at Sin-Le-Noble, Nord France.</i> By S. Weiner and E. Aslaksen.	Dec. 1952 38	Power Statistics	
Greenwich Steam Generating Station, Atlantic City Electric Company. <i>Greenwich Steam Generating Station of Atlantic City Electric Co.</i> By V. J. Feeney.	Apr. 1953 40	Steam and Electric Power—Its Past and Future. By Theodore Baumeister.	Oct. 1952 41
Kearny Generating Station, Public Service Electric & Gas Co. <i>New Kearny Station in Service.</i>	May 1953 40		

	PAGE
Pulverized Fuel	
Burning Pulverized Cinders, <i>ASME Spring Meeting</i> . By John M. Allen.....May 1953	59
Mill Drying in Pulverizing High-Moisture Coals, <i>ASME Spring Meeting</i> . By Wayne C. Rogers.....May 1953	57
Pumps	
Minimum Continuous Safe Flow of Centrifugal Pumps. By E. C. Condict.....Aug. 1952	55
Pumps for Handling Liquid Metals, <i>ASME Annual Meeting</i> . By Philip M. Clark and J. F. Cage, Jr.....Dec. 1952	58
Reheat	
3,000,000 Kw Operating Experience with Modern Re- heat. By Otto de Lorenzi.....May 1953	47
Slag	
Additives to Fuel Oil, Part I, <i>ASME Annual Meeting</i> . By J. B. Mellroy and E. J. Holler, Jr.....Dec. 1952	62
Additives to Fuel Oil, Part II, <i>ASME Annual Meeting</i> . By R. Lee.....Dec. 1952	62
Use of Pellets for Slag Removal, <i>ASME Annual Meet- ing</i> . By W. F. Cantieri.....Dec. 1952	64
Steam	
Effect of Operating Pressure on Carbon Dioxide Content of Steam, <i>Thirteenth Annual Water Conference</i> . By J. J. Maguire and R. E. Winston.....Nov. 1952	56
New Steam Table Up to 700 C. By Dip. Ing. H. Ery- thropel.....Mar. 1953	55
Steam Turbine-Generators	
Cross-Compound Designs, <i>American Power Conference</i> . By Charles D. Wilson.....Apr. 1953	49
Design and Application of Large Steam Turbines, <i>American Power Conference</i> . By Carl Schabtaeh, C. E. Kilbourne and J. B. McClure.....Apr. 1953	48
Development of the 3600-rpm Turbine, <i>American Power Conference</i> . By H. R. Reese.....Apr. 1953	48
Elastic-Fluid Centripetal Turbine for High Specific Outputs, <i>ASME Spring Meeting</i> . By Rudolph Bir- mann.....May 1953	54
Inner-Cooled Turbine-Generators, <i>American Power Conference</i> . By J. W. Batchelor.....Apr. 1953	50
Present Status of Supercharged Cooling, <i>American Power Conference</i> . By W. L. Ringland and L. T. Rosenberg.....Apr. 1953	49
Prevention of Metal Losses in the Wet Steam Areas of Steam Turbines, <i>American Power Conference</i> . By F. L. Archibald, J. W. Pursell, Jr., and F. G. Straub.....Apr. 1953	51
Quick Starting of Large High-Pressure, High-Tempera- ture Boilers, <i>ASME Annual Meeting</i> . By J. C. Falk- ner.....Dec. 1952	53
Quick Starting of Turbines, <i>ASME Annual Meeting</i> . By C. W. Elston.....Dec. 1952	54
Some Theoretical Aspects of Centripetal Turbines, <i>ASME Spring Meeting</i> . By Richard L. Robinson.....May 1953	55
Stokers	
Application and Performance of Single-Retort, Under- feed Stokers, <i>ASME Annual Meeting</i> . By E. C. Webb and J. E. Atchinson.....Dec. 1952	58
Breaker Bars for Traveling Grate Stokers. By Walter Greacen III.....Nov. 1952	43
Dust Emissions from Small Spreader-Stoker-Fired Boilers, <i>ASME Spring Meeting</i> . By E. J. Boer and C. W. Porterfield.....May 1953	58
Operating Spreader Stokers. By Leo J. Cohan.....Oct. 1952	64
Present-Day Thoughts on the Application of Single- Retort, Underfeed Stokers, <i>ASME Annual Meeting</i> . By D. J. Mosshart.....Dec. 1952	58
Relation of Spreader Stokers to Air Pollution. By Max O. Funk.....July 1952	41
Turbulent Suspension Burning. By Otto de Lorenzi.....Feb. 1953	55
Superheaters	
Superheater Tube Temperature Measurements. By T. W. Jenkins, Jr.....Apr. 1953	59
Superheater Tubing Materials for High Temperatures, <i>ASME Annual Meeting</i> . By C. J. Slunder, A. M. Hall and J. H. Jackson.....Dec. 1952	60
Synthetic Fuels	
Advances in Synthetic Fuels Technology.....Feb. 1953	66

Television

Experience with Furnace Television. By L. M. Exley.....Nov. 1952	63
--	----

Waste Heat

Improved Utilization of Waste Heat. By Dr. Richard Dolezal.....Sept. 1952	57
--	----

Water Conditioning

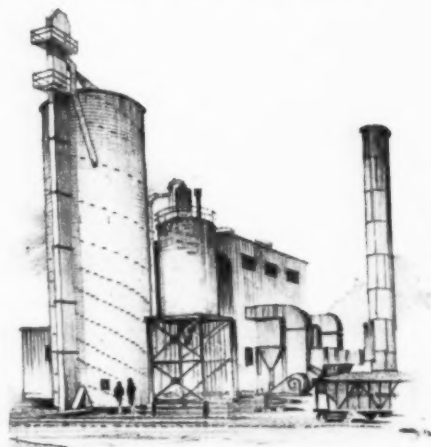
Acid Regeneration of Cation Exchangers, <i>American Power Conference</i> . By F. K. Lindsay.....Apr. 1953	53
Application of Metallic Phosphates to Cooling Water Treatment, <i>Thirteenth Annual Water Conference</i> . By William J. Stone.....Nov. 1952	55
Condensate Contamination, <i>ASME Annual Meeting</i> . By J. D. Ristoph and E. B. Powell.....Dec. 1952	63
Control of Resinous Materials in Low-Pressure Boilers, <i>Thirteenth Annual Water Conference</i> . By W. L. An- drews.....Nov. 1952	56
Conversion of a Two-Stage Hot Process Water Softener from Hot Lime-Soda Phosphate to Hot Lime Zeolite at Cambridge Electric Light Co., <i>ASME Annual Meeting</i> . By G. H. Gowdy and S. B. Applebaum.....Dec. 1952	63
Deionization Vs. Evaporation of Hard Water Supplies for Boiler Makeup, <i>Thirteenth Annual Water Confer- ence</i> . By T. C. Hoppe and R. A. Russell.....Nov. 1952	54
Demineralizing Experience, <i>ASME Fall Meeting</i> . By V. B. Burgess and D. N. Purcell.....Oct. 1952	46
Economics, the Key to Evaporation Vs. Demineraliza- tion for Makeup in High-Pressure Steam Power Plants, <i>American Power Conference</i> . By E. B. Morris and C. E. Brune.....Apr. 1953	53
Experience with Amines, <i>American Power Conference</i> . By H. J. Guillory.....Apr. 1953	53
Experiences with Application of Deaerating Heaters in Feedwater Cycles, <i>Thirteenth Annual Water Confer- ence</i> . By V. J. Calise and R. K. Stenard.....Nov. 1952	54
Experiences with Chloride Anion Exchangers for Re- ducing Alkalinity Without Acid, <i>Thirteenth Annual Water Conference</i> . By S. B. Applebaum.....Nov. 1952	53
Feedwater Conditioning by Evaporation, <i>American Power Conference</i> . By A. M. Impagliazzo.....Apr. 1953	52
Removal of Oil from Condensate by Diatomite Filtra- tion, <i>Thirteenth Annual Water Conference</i> . By G. R. Bell.....Nov. 1952	56
Solubility of Oxygen in Water, <i>The ASME Spring Meeting</i> . By L. M. Zoss, S. Suciu and W. L. Sibbitt.....May 1953	56
Study of Reducing Solutions at Steam Boiler Tempera- tures, A. By Harry D. Ongman.....Feb. 1953	40
Thirteenth Annual Water Conference.....Nov. 1952	53

Miscellaneous

AIEE Winter General Meeting.....Feb. 1953	61
American Power Conference Program.....Mar. 1953	59
ASME Annual Meeting Program Briefed.....Nov. 1952	59
ASME Spring Meeting Program.....Apr. 1953	65
Are Federal Power Practices Sound National Policy? <i>American Power Conference</i> . By E. R. de Luccia.....Apr. 1953	54
Century of Engineering Progress Marked by Chicago Meeting.....Oct. 1952	40
Cincinnati Host to ASME Semi-Annual Meeting.....July 1952	37
Classification of Outages of Facilities in Electric Power Systems, A. By Arnold Rich.....Mar. 1953	43
Cooling Towers, Panel Discussion, <i>Thirteenth Annual Water Conference</i> : J. S. Hill, George Illig, J. F. Wilkes and J. K. Rice.....Nov. 1952	55
Design for Extreme Flood Conditions at the Paddy's Run Station, <i>ASME Semi-Annual Meeting</i> . By D. C. Hormell.....July 1952	39
District Heating, <i>Century of Engineering</i> . By A. R. Mumford.....Oct. 1952	41
Engineering Economy in the Electric Utility Industry. By K. M. Irwin.....Sept. 1952	53
Furnace-Heat Absorption Efficiency as Shown by En- thalpy of Gases Leaving the Furnace, <i>ASME Annual Meeting</i> . By J. W. Myers and R. C. Corey.....Dec. 1952	56
Handling Material for the Walter C. Beckjord Station. By Raymond F. Schierland.....Aug. 1952	51
Heard at the ASME Annual Meeting.....Dec. 1952	53
High Pressure Hot Water at Air Bases.....June 1953	59
Mechanical Engineers to Participate in Century of Engineering.....Aug. 1952	57
Metals and Metal Processing in the Atomic Energy Field. By Alan U. Seybolt.....July 1952	47
New Features of Steam Plants on Inland Rivers, <i>ASME Semi-Annual Meeting</i> . By G. V. Williamson.....July 1952	39
1953 American Power Conference.....Apr. 1953	47
Overfire Air Installation at the Connors Creek Power Plant, <i>ASME Spring Meeting</i> . By James W. Camp- bell and Richard J. Travis.....May 1953	56
Past Progress and Present Trends in the Art of Power Generation, <i>Century of Engineering</i> . By A. C. Mon- teith and A. A. Johnson.....Oct. 1952	41
Power Activity in 1952.....Jan. 1953	43

	PAGE		PAGE
Prime Mover Advances Feature ASME Spring Meeting.....	May 1953 53	Economics of Natural Gas in Texas. By John R. Stockton, Richard C. Henshaw, Jr., and Richard W. Graves.....	Mar. 1953 65
Progress and Future Trends in Electric Transmission, <i>Century of Engineering</i> . By S. B. Cary, I. W. Gross and C. F. Wagner.....	Oct. 1952 42	Elementary Heat Power, Second Edition. By H. L. Solberg, O. C. Cromer and A. R. Spalding.....	Nov. 1952 69
Steam and Electric Power—Its Past and Future. By Theodore Baumeister.....	Dec. 1952 45	Elements of Nuclear Reactor Theory, The. By Samuel Glasstone and M. C. Edlund.....	Apr. 1953 69
Thermal Shock and Other Comparison Tests of Austenitic and Ferritic Steels for Main Steam Piping, <i>ASME Annual Meeting</i> . By W. C. Stewart and W. G. Schreitz.....	Dec. 1952 63	Engineers as Writers. By W. J. Miller and L. E. A. Saidla.....	June 1953 63
Training Power Plant Personnel, A Symposium, <i>ASME Semi-Annual Meeting</i> : F. E. Nicoson, J. D. Williamson, Albert H. Beiler, John E. Geue, D. F. Steinke and Vern L. Stone.....	July 1952 37	Fuels and Combustion. By M. L. Smith and K. W. Stinson.....	Dec. 1952 71
Variation in Furnace Heat Absorption as Shown by Measurement of Temperature of Exposed Side of Furnace Tubes, <i>ASME Annual Meeting</i> . By F. G. Feeley Jr., and Earle C. Miller.....	Dec. 1952 57	Gas Turbine Power. By G. M. Dushinberre.....	Dec. 1952 73
REVIEW OF NEW BOOKS		Handbook of Engineering Fundamentals. Edited by O. W. Eshbach.....	Aug. 1952 58
Advanced Mathematics in Physics and Engineering. By Arthur Bronwell.....	Apr. 1953 67	Heat Transfer Phenomena. By R. C. L. Bosworth.....	Mar. 1953 65
Air Pollution. Proceedings of the U. S. Technical Conference on Air Pollution.....	Dec. 1952 72	Interchangeability of Oil Gas and Natural Gas. By D. L. Nicol, R. A. Brown and H. R. Linden.....	Nov. 1952 69
All-Purpose Diesels. By J. M. Robson.....	Dec. 1952 73	Les Machines Thermiques. By Paul Chambadal.....	Nov. 1952 69
American Electricians' Handbook. By Terrell Croft.....	June 1952 63	Methods of Analysis of Fuels and Oils. By J. R. Campbell.....	Aug. 1952 58
American Pipe Lines. By George S. Wolbert, Jr.....	Nov. 1952 69	Science of Flames and Furnaces, The. By M. W. Thring.....	Dec. 1952 71
Atmospheric Pollution—Its Origins and Preventions. By A. R. Meetham.....	Apr. 1953 67	Selection of Oils for Carbureted Water Gas (Bulletin No. 9) and Selection of Oils for High-Btu Oil Gas (Bulletin No. 12). Published by the Institute of Gas Technology.....	Aug. 1952 59
Atomic Power. By Walter Isard and Vincent Whitney.....	June 1953 63	Specifications for Steel Piping. Published by The American Society for Testing Materials.....	Apr. 1952 68
Basic Mechanics of Fluids. By Hunter Ronse and J. W. Howe.....	June 1953 63	Steam Power Plants. By A. H. Zerban and E. P. Nye.....	Aug. 1952 58
Coal Manual for Industry. By A. Wyn Williams.....	Apr. 1953 67	Steam Power Stations, Fourth Edition. By Gustav A. Gaffert.....	Nov. 1952 69
Code for Protection Against Lightning. Published by the National Bureau of Standards.....	Mar. 1953 67	Surface Condenser Standards. Published by The Heat Exchange Institute.....	Apr. 1953 70
Combustion Handbook. Published by the North American Mfg. Co.....	Aug. 1952 59	Technical Calculations in Heat Engineering. By James H. Potter.....	Nov. 1952 69
		Technique of Clear Writing. By Robert Gunning.....	Aug. 1952 60
		Thermodynamic Properties of Nitrogen. Published by the Institute of Gas Technology.....	Mar. 1953 66
		Thermodynamics in an Engineering Curriculum. By Myron Tribus.....	Aug. 1952 58

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